THE 2011 UNIVERSITY OF ILLINOIS

Corn & Soybean Classic

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College of Agricultural, Consumer and Environmental Sciences
Department of Crop Sciences

Paying for Fungicides, or Making Fungicides pay?

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The use of foliar fungicides on corn and soybean has increased dramatically over the last few years. Fungicides can be valuable tools that can be used to protect crops against plant diseases, which helps producers be more profitable. However, when the use of fungicides is not warranted under low disease pressure situations, they are much more likely to result into an added expense and not added profits. Trials have been conducted by the University of Illinois in the past few years to help determine when fungicide applications are more likely to be profitable. The following paper discusses the results of trials conducted during the 2010 growing season.

Corn Fungicide Trials in Illinois

Disease pressure and corn yield response to foliar fungicides. A uniform set of fungicide treatments were applied to corn (growth stage R1) in research trials located at six locations in Illinois (Auburn, DeKalb, Dixon Springs, Monmouth, Perry, and Urbana), and evaluated for their effect on yield in 2010. Averaged over all fungicide treatments and locations, the overall yield response was 8 bu/A, with yield responses ranging from –12 to 28 bu/A (Fig. 1). Disease pressure varied by location. The DeKalb location had the least amount of disease pressure (3% severity), while the Auburn location had the highest amount of disease pressure (48% severity). In general, the highest yield responses to fungicides occurred at locations with the highest disease pressure. At locations where disease severity was less than 10%, yield responses were generally less than 10 bu/A. These results indicate that disease severity plays a large role in corn's yield response to fungicides.

Application timing trials. Prior to and during the 2010 growing season, foliar fungicide applications to corn at the V4–V6 growth stages were aggressively marketed by some companies. Prior to 2010, very few university field trials had been conducted in Illinois and surrounding states where fungicides applied to V4–V6 stage were evaluated. In 2010, field trials were conducted at Urbana and Monmouth, IL to evaluate the effect of fungicides applied at different timings to corn on disease control and yield. At Urbana, different fungicide products were evaluated at 3 different timings: V6, R1, and V6 followed by R1. At Monmouth, Headline fungicide was evaluated at 4 different timings: V5, V15, VT, and R1. At Urbana, very low disease pressure was observed throughout the trial (2% severity and less), and no statistically significant differences in disease or yield were observed across all of the different treatments (Table 1). At Monmouth, high disease pressure was observed (66% severity in the non-treated control). Disease severity was significantly reduced by Headline fungicide applications made at VT or R1, but not by applications made at V5 or V15 when compared to the non-treated control. Headline fungicide applications made to VT or R1 corn provided significantly greater yields than the non-treated control or applications made to V5 or V15 corn.

Soybean Fungicide Trials in Illinois

Multi-site fungicide trial. Foliar fungicide trials were conducted on soybean at six different locations in Illinois (Belleville, DeKalb, Monmouth, Perry, Ridgway, and Urbana) in 2010. The overall average yield response across all locations was 1 bu/A (Fig. 2). Yield responses ranged from –10 to 9 bu/A. In

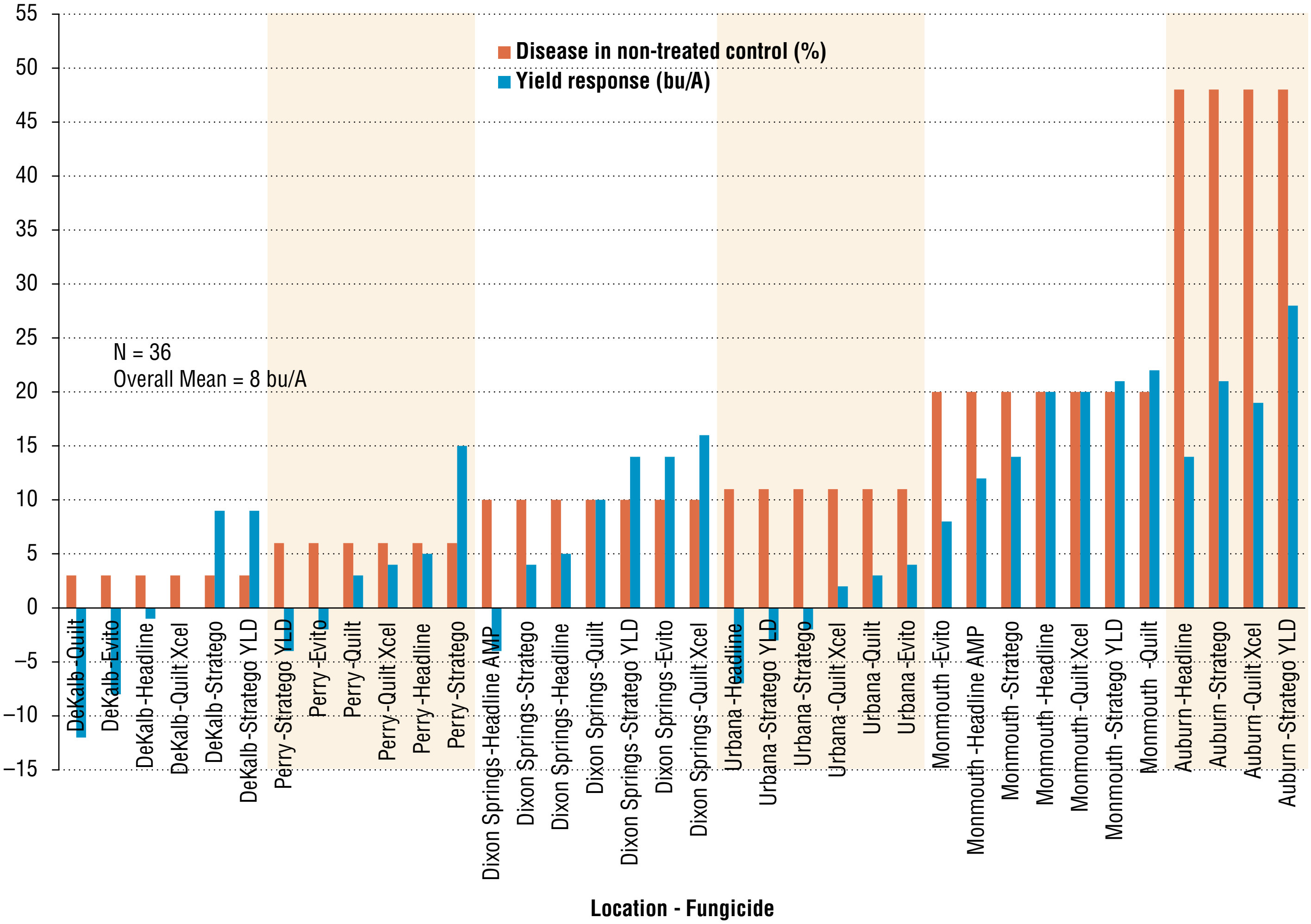

Figure 1 ■ Results of 2010 corn foliar fungicide trials in Illinois.

general, yield responses were consistently positive or not negative at locations with frogeye leaf spot levels of at least 2%.

Cultivar × fungicide trial with high frogeye leaf spot pressure. A foliar fungicide trial was conducted at Belleville, IL in 2010 with four different soybean cultivars. One cultivar (FS 4366) was susceptible to frogeye leaf spot (*Cercospora sojina*), while the other three cultivars were resistant to frogeye leaf spot. Significant yield responses to foliar fungicides were observed only on the frogeye leaf spot-susceptible cultivar (Table 2), and not on the other three cultivars. These results indicate that frogeye leaf spot may be able to cause yield reductions to soybean in Illinois on susceptible cultivars when conditions are favorable for disease. In addition, these results indicate that fungicides did not increase yield on cultivars that were not affected by frogeye leaf spot.

Fungicide Resistance Risk and Management in Illinois

Strobilurin fungicide-resistant *Cercospora sojina*. In 2010, isolates of *Cercospora sojina* (causal agent of frogeye leaf spot) were collected from a soybean field in Tennessee that were found to be resistant to quinone outside inhibitor (QoI—also known as strobilurin) fungicides. To date, this is the only

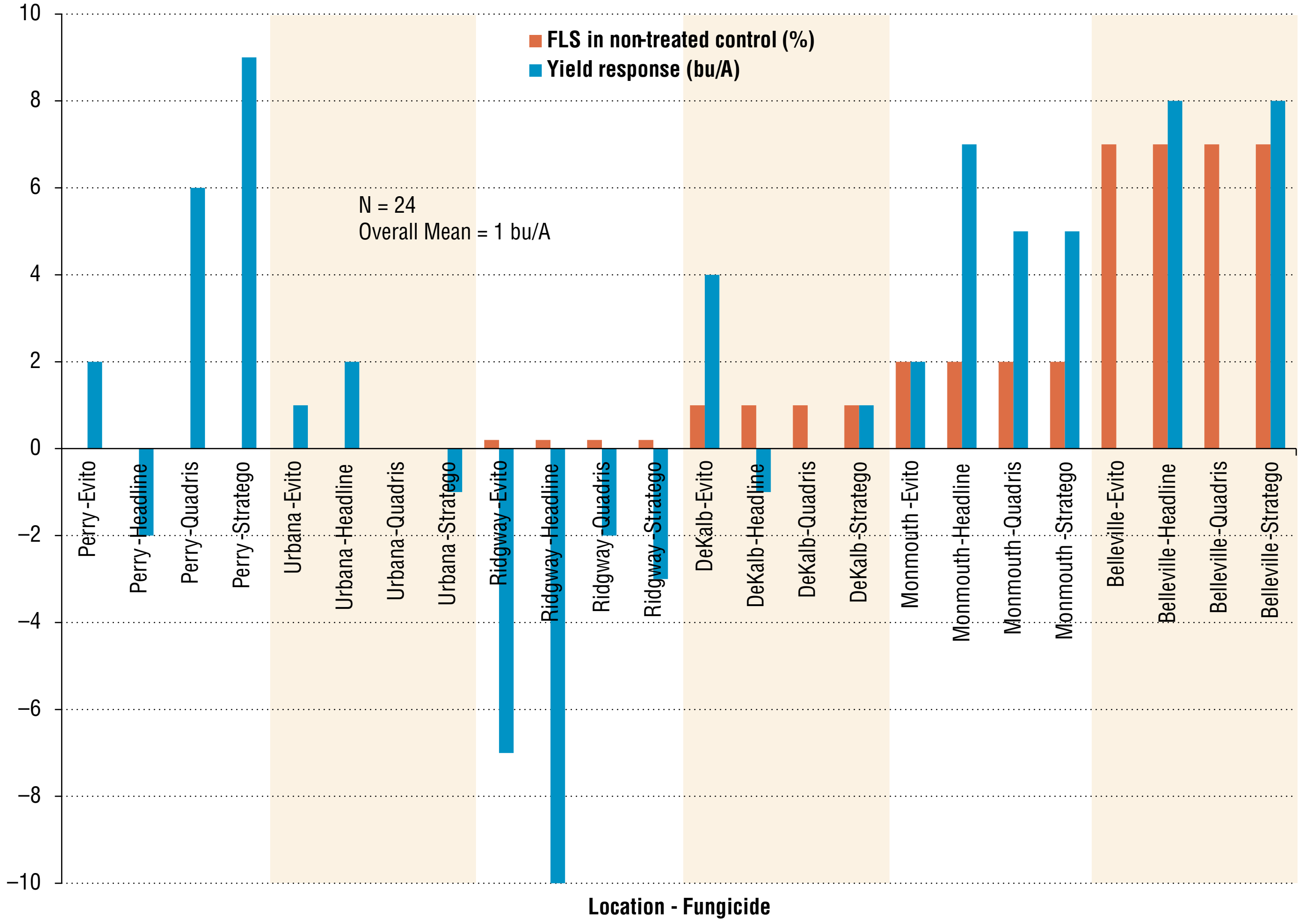

Figure 2 ■ Results of 2010 soybean foliar fungicide trials in Illinois.

documented field that has been found to have strobilurin-resistant strains of the frogeye leaf spot fungus; however, it is likely that similar strains are present elsewhere. To prevent the spread and development of strobilurin fungicide-resistant *C. sojina*, it is important to do the following:

1. Plant soybean cultivars with resistance to frogeye leaf spot.
2. If a susceptible cultivar has been planted, and a fungicide application is being considered, then apply an effective triazole fungicide for control.
3. In situations where other foliar diseases may be present along with frogeye leaf spot, and a strobilurin fungicide may be needed to control the other foliar diseases, do not spray a solo strobilurin product. Either apply a strobilurin-triazole tank-mix, or apply a product that contains both a strobilurin and a triazole fungicide.
4. Only apply a foliar fungicide when warranted for disease control.

Conclusions

Fungicides have become important tools used in corn and soybean production in Illinois. For the most profitable use of fungicides, it is important to apply these based on disease risk and scouting observations. When applying for

Table 1 ■ Effect of foliar fungicides applied to corn at different timings on disease severity and yield at Urbana and Monmouth, IL in 2010.

Location	Fungicide	Application timing	Disease severity (%)*	Yield (bu/A)*
Urbana	Non-treated control	—	2.0 A	110 A
	Quilt Xcel 10.5 fl oz	V6	0.8 A	127 A
	Quilt Xcel 10.5 fl oz	R1	0.5 A	127 A
	Quilt Xcel 10.5 fl oz / Quilt Xcel 10.5 fl oz	V6/R1	0.8 A	113 A
	Headline AMP 10 fl oz	V6	1.0 A	129 A
	Headline AMP 10 fl oz	R1	0.5 A	123 A
	Headline AMP 10 fl oz / Headline AMP 10 fl oz	V6/R1	0.8 A	129 A
	Evito 2 fl oz	V6	0.8 A	131 A
	Evito 2 fl oz	R1	0.8 A	125 A
	Evito 2 fl oz / Evito 2 fl oz	V6/R1	1.0 A	127 A
	Stratego 2.5 fl oz/A	V6	1.0 A	119 A
	Stratego 5 fl oz/A	R1	0.5 A	129 A
	Stratego 2.5 fl oz / Stratego 5 fl oz	V6/R1	0.8 A	127 A
Monmouth	Non-treated control	—	66 B	229 A
	Headline 6 fl oz	V5	65 B	234 AB
	Headline 6 fl oz	V15	63 B	239 B
	Headline 6 fl oz	VT	33 A	253 C
	Headline 6 fl oz	R1	26 A	252 C

*Values within a column and location followed by the same letter are not significantly different with 95% confidence.

Table 2 ■ Effect of foliar fungicides on soybean cultivars differing in susceptibility to frogeye leaf spot at Belleville, IL in 2010.

Cultivar	Fungicide	Frogeye leaf spot incidence (%)	Yield (bu/A)
FS 4366	Non-treated control	88	60
	Headline 6 fl oz	22*	71*
	Stratego 10 fl oz	7*	83*
	TopGuard	22*	66
	Domark	50*	62
Pioneer 94Y70	Non-treated control	0	64
	Headline 6 fl oz	0	74
	Stratego 10 fl oz	0	69
	TopGuard	0	72
	Domark	0	65
FS 45T70	Non-treated control	0	68
	Headline 6 fl oz	0	74
	Stratego 10 fl oz	0	70
	TopGuard	0	70
	Domark	0	72
Stone 3A449 NRRRSTS	Non-treated control	0	73
	Headline 6 fl oz	0	75
	Stratego 10 fl oz	0	73
	TopGuard	0	74
	Domark	0	74

*Denotes that value is significantly different than the non-treated control for that cultivar (95% confidence level).

reasons other than disease control, the benefits of fungicides are inconsistent. In addition, use of fungicides for reasons other than disease control could potentially increase the development and spread of fungicide-resistant strains of fungal pathogens.

Acknowledgements

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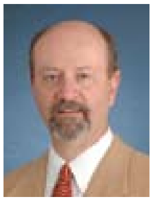
0%, 5%, 10%, or 20%: Stacked or Pyramided, Structured or Refuge-in-a-Bag—Perfectly Clear?



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Bt Use in Illinois in 2010

In 2010, the use of "stacked gene varieties" declined 7% in Illinois from the previous year of 59%, matching the 52% level in 2008 (USDA ERS; www.ers.usda.gov/Data/BiotechCrops/). In contrast, small increases in the use of stacked gene varieties occurred in some other major corn producing states such as Indiana (55% to 56%), Iowa (57% to 61%), and Nebraska (42% to 45%). The use of "insect-resistant (Bt) only" corn hybrids increased from 10% to 15% in Illinois from 2009 to 2010. Overall use of genetically engineered varieties in Illinois decreased 2% from 2009 (84%) to 2010 (82%). Reasons for the decline in the use of stacked corn hybrids in Illinois during 2010 may relate to concern over seed cost and/or the perceived lack of yield benefit in the absence of economic densities of certain insect pests. Despite this reduction in the use of stacked corn hybrids, approximately one-half of the Illinois' corn acres were devoted to this technology. Will a downward trend begin to develop in the use of stacked Bt corn hybrids or is this just a 1-year aberration? Many factors will influence the answer to this question such as seed cost, commodity prices, anticipated pest pressure, perceived competitiveness of stacked corn hybrids, and availability of elite high-yielding germplasm in non-stacked corn hybrids.

Do I Need to Use a Bt Hybrid in 2011?

The densities of western corn rootworms and the once prominent European corn borer were very low across Illinois' cornfields in 2010. This is not a surprise for the European corn borer since numbers of this insect pest have reached historic lows in Illinois for many consecutive years. However, the low densities of western corn rootworm adults did have many entomologists, crop consultants, producers, and agribusiness personnel searching for explanations. The lack of economic infestations of western corn rootworms is most likely attributable to back-to-back wet springs at the time of larval hatch (late-May, early-June) in 2009 and 2010, the widespread broadcast applications of tank-mixed fungicides and insecticides in corn and soybean fields in recent years, and the increased use of Bt corn and/or soil insecticides on rotated and non-rotated corn acres. Consequently, corn growers are making decisions regarding the need for Bt corn targeted primarily at western corn rootworms and/or the lepidopteran complex in 2011. Specifically, will an increased investment in this transgenic technology pay dividends? Or, are producers purchasing primarily insect insurance and peace of mind? Professor Joe Lauer, University of Wisconsin Extension Corn Agronomist, offered the following guidelines in selecting a hybrid (*Wisconsin Crop Manager*, October 11, 2010): "1. Use multi-location averages to compare hybrids, 2) Evaluate consistency of performance, 3) Buy the traits you need, 4) Every hybrid must stand on its own, and 5) Pay attention to seed costs." Of these five, number 3 may be resonating with producers who witnessed low densities of several key insect pests of corn in 2010.

Nonetheless, from an overall regional perspective, the economic benefits of Bt corn are impressive. Since the introduction of Bt corn into the market place in 1996, corn producers have made significant economic gains related to the areawide suppression of European corn borers. According to a paper published in *Science* (October 8, 2010), cumulative benefits for corn growers, due to widespread use of Bt hybrids during a 14-year period in Illinois, Minnesota, and Wisconsin were $3.2 billion. Of special interest is the estimate that more than $2.4 billion of this total went to producers who elected not to plant Bt corn. Similarly, cumulative benefits for Iowa and Nebraska corn producers were $3.6 billion (total) with $1.9 billion accruing to producers who used non-Bt hybrids. In essence, producers who elected not to use Bt hybrids saved money by not purchasing more expensive seed and also benefited due to the lower densities of European corn borer across a regional landscape because of the increasing use of Bt hybrids by their neighbors.

Before making any final decisions about seed selection for 2011, keep in mind that there are no effective rescue treatments for corn rootworms. So, despite the low densities of western corn rootworms in 2010, that doesn't mean all fields will have similar low numbers in 2011. Corn rootworm management decisions must be made on a field by field basis. Most producers do not scout their fields adequately for western corn rootworm adults and consequently cannot accurately estimate the likelihood of an economic infestation the following season. Therefore, if a producer decides not to purchase a Bt corn rootworm hybrid and has little scouting information to base this decision upon, then the use of a corn rootworm soil insecticide delivered at-planting is the prudent course of action. This recommendation holds true for continuous corn and for those areas where the rotation resistant western corn rootworm is firmly entrenched. Simply put, there is too much at risk under this scenario not to protect the investment in corn against this potentially devastating insect pest. With respect to the purchase of Bt hybrids that offer broad-spectrum lepidopteran protection (black cutworm, European corn borer, fall armyworm, western bean cutworm), rescue treatments that are timely and triggered by careful scouting efforts can work effectively to limit potential economic losses. However, producers have to be committed to this traditional integrated pest management (IPM) approach. Recent trends suggest that most large-scale commercial corn producers are not.

Structured Refuges vs. Refuge-in-a-Bag

To date, no confirmed cases of field-evolved resistance to Bt corn by western corn rootworms or European corn borers have occurred in the Corn Belt. Considering this technology has been in the market place for 15 growing seasons and remains the predominant corn insect management strategy in the North Central Region of the U.S., perhaps we should be surprised that resistance has not yet occurred. At last year's *Corn and Soybean Classics*, I reported on several cases of field-evolved resistance to Bt that included: 1) some populations of corn earworms in Arkansas and Mississippi to Bt cotton expressing the Cry1Ac protein, and 2) fall armyworm resistance to Bt corn expressing the Cry1F protein in Puerto Rico. As the widespread use of Bt corn continues and the duration of exposure (many growing seasons) to corn insects increases, the potential development of resistance becomes magnified. This accentuates the importance of refuge compliance by corn producers. Recently, published studies indicate that refuge compliance has been slipping compared with earlier adoption rates. Fueling the lack of adequate compliance is confusion on the part of producers regarding the appropriate refuge to deploy for a given Bt hybrid. As the refuge requirements in Table 1 indicate, one-size refuge does not fit all Bt corn.

In 2009, a report titled *Complaceny on the Farm*, was published by the Center for Science in the Public Interest, Washington, D.C. The author (Gregory Jaffe, Director of the CSPI Biotechnology Project) of the report utilized refuge compliance data collected by registrants of Bt products. Registrants are required to collect these data annually and prepare a summary, the Compliance Assurance Program Report (CAP Report), which is subsequently submitted to the U.S. Environmental Protection Agency. The CSPI report indicated that refuge compliance was above 90% from 2003 to 2005. Unfortunately, by 2008 roughly 25% of producers who utilized Bt corn were out of compliance. During this time frame, the CSPI Report, also indicated that the number of corn acres out of compliance increased from 2.29 million acres to 13.23 million acres. On-farm audits by industry personnel did reveal greater levels of compliance than surveys; however, the trends were similar. Refuge compliance in 2008 and 2009 for producers participating in the *Corn and Soybean Classics* was estimated at 82% and 75.7%, respectively (*Journal of Agricultural and Food Chemistry*, DOI: 10.1021/jf102673s). The 2009 estimate closely matches the percentage of noncompliance reported in the CSPI document for 2008. Because the EPA considers the sustainability of Bt insecticidal proteins a "public good," declining refuge compliance should cause some concern across the agribusiness and farming communities, as well as the general public.

Until the 2010 growing season unfolded, a structured 20% refuge requirement was the primary resistance management option for insect pests within the Corn Belt of the U.S. Despite the fact that many Bt hybrids still require a 20% structured refuge, two significant U.S. E.P.A. registration developments have shaken the status quo of this refuge requirement: 1) the 5% structured refuge for SmartStax™ (Mycogen or Genuity) hybrids for corn rootworms and lepidopteran pests and Genuity® VT Double Pro™ (VT2P) hybrids exclusively for lepidopteran pests (Table 1), and 2) the 10% refuge-in-a-bag for Optimum® AcreMax™1 and Optimum® AcreMax™ RW hybrids (Table 1). Producers have many options with respect to Bt hybrids they can plant and one criterion that will surely factor into their decision is the specific refuge requirement for the Bt hybrid of their choice.

At the 2010 *Corn and Soybean Classics*, 80.4% of producers indicated they would be willing to use a seed blend (Bt and non-Bt) as their refuge. Of those producers who expressed an interest in the refuge-in-a-bag approach, 90% indicated they would use a seed blend that contained non-Bt seed in the 2% to 5% range. However, that percentage declined to 53.1% when the non-Bt seed fell within the range of 6% to 10%. These results reveal high levels of receptiveness to the refuge-in-a-bag approach; however, there is concern regarding the level of non-Bt seed above 5%. In my opinion, I think there will be a gradual shift by the seed industry to the seed mixture (Bt and non-Bt) refuge strategy as more pyramided (multiple insecticidal proteins expressed against a specific insect pest) Bt hybrids are registered and the U.S. E.P.A. becomes increasingly concerned about the rising lack of refuge compliance. The seed mixture refuge strategy ensures compliance and reduces many logistical "headaches." In addition, producers are receptive and find this approach very convenient. However, will the use of a seed mixture strategy prove superior to structured refuges when it comes to preventing or delaying resistance development to Bt insecticidal proteins? One thing seems certain—if the deployment of structured refuges continues to decline, then seed mixtures may prove the only realistic alternative resistance management approach.

In 2010, Pioneer Hi-Bred International, Inc., indicated to U.S. E.P.A. that approximately 34,804 acres were planted to Optimum® AcreMax™1 (OAM 1) corn hybrids (Biopesticides Registration Action Document, *Optimum® AcreMax™ B.t. Corn Seed Blend*s, U.S. E.P.A., September 2010, 23 pages). This is a very small percentage of the U.S. Corn Belt; however, Pioneer projects that by 2012, roughly 8% and 12% of the U.S. corn acreage will be devoted to OAM1 hybrids in "red zone" and "non-red" zone geographies, respectively. The red zone geography consists of 90 counties in northeastern Illinois, northwestern Indiana, and southeastern Wisconsin and is regarded as an area of intense selection pressure. How durable is the OAM1 refuge-in-a-bag approach to resistance management as projected by the U.S. E.P.A.? The following quote was taken from page 13 of the Biopesticides Registration Action Document: "The durability outputs that EPA determined for the proposed 90% CRW protected seed/10% non-CRW protected seed blend, and a 20% block refuge are 11.3 years to resistance, and 20.2 years to resistance, respectively. Thus, our analysis indicated that, as modeled, the proposed seed blend is 45% less durable on a comparative basis than the 20% block refuge currently required for single trait CRW PIPs." The acronynm PIP stands for plant incorporated protectant (pesticidal compounds produced by plants). In addition, the U.S. E.P.A. acknowledged (page 13) the following concern of other registrants that utilize Cry34/35Ab1 in their Bt hybrids: "Based on our assessment, we concluded that significant acreage of a 10% seed blend with a single, non-high dose mode of action such as Cry34/35Ab1 likely increases the risk of resistance for all B.t corn products containing Cry34/35Ab1." As part of this renewed registration, Pioneer is expected to fulfill the following requirements: 1) " … to implement an enhanced resistance monitoring plan for OAM1 that included benchmark studies showing susceptibility of the western corn rootworm populations" … 2) "These studies must be submitted by December 1, 2010." 3) "Pioneer must also submit by December 1, 2010, a detailed OAM1-specific resistance monitoring and remedial action plan," …. and 4) "Pioneer was also required to develop programs to evaluate whether there are statistically significant and biologically relevant changes in target insect susceptibility to Cry1F and Cry34Ab1/Cry35Ab1 proteins in the target insects; and a remedial action plan that must set forth the specific measures Pioneer will take in the event that any field-relevant insect resistance is detected." Because U.S. E.P.A. did not believe the OAM1 refuge-in-a-bag approach was as durable (in preventing or delaying resistance) as the 20% structured refuge (for a single toxin product), a five-year registration was not offered and instead, the registration is set to expire on September 30, 2012. As more pyramided Bt hybrids become available, the U.S. E.P.A. will continue to evaluate the benefits and risks of offering registrations to registrants that want to commercialize hybrids with 95% (Bt) and 5% (non-Bt) seed blends. Confusion regarding refuge requirements for the great diversity of hybrids will become an increasing certainty. Consequently, U.S. E.P.A. is requiring registrants to place refuge requirements on seed bags—"make best efforts to implement this change on as many bags of seed as possible for the 2011 growing season, on 50% of seed bags for the 2012 growing season, and on 100% of seed bags for the 2013 growing season." From my perspective, this is a positive development.

Stacked vs. Pyramided Hybrids

Some confusion persists concerning the terms "stacked" and "pyramided." Simply put, U.S. E.P.A. has defined pyramided Bt products as "products containing two or more toxins efficacious against the same pest"; whereas, stacked products are "products combining toxins efficacious against different pests." A body of research has begun to emerge that suggests pyramiding genes within transgenic plants may prevent or delay resistance to Cry proteins more effectively than use of transgenic plants expressing a single transgene. Thus far, Bt corn marketed as SmartStax™ Hybrids (Mycogen or Genuity), represents the most well known pyramided product that has been introduced into the marketplace (Table 1) with multiple proteins targeted at both corn rootworms (Cry3Bb1, Cry34Ab1/Cry35Ab1) and lepidopteran (Cry1A.105 + Cry2Ab2, Cry1F) pests. In addition, Agrisure®Viptera™ 3111 corn hybrids are pyramided with plants expressing both the Cry1Ab and Vip3Aa20 proteins against lepidopteran pests (Table 1). However, unlike SmartStax™ Hybrids, only a single mCry3a protein is expressed against corn rootworms.

Is the distinction among hybrids characterized by these terms (stacked vs. pyramided) important? From a U.S. E.P.A. regulatory vantage point, the answer to this question is "yes." The U.S. E.P.A. (Biopesticides Registration Action Document, *Optimum® AcreMax™ B.t. Corn Seed Blend*s, U.S. E.P.A., September 2010, 23 pages) provided the following rationale on this subject (page 19): … "where we've determined that a particular product, or category of products, likely will pose less risk of insect resistance developing to a particular PIP protein, we think it appropriate to grant that particular product, or category of products, a registration for a period greater that that granted a corresponding product that poses a greater risk of insect resistance developing." Based upon this logic, the U.S. E.P.A. will use the following regulatory system:

- "(i) a product with a single PIP toxin, and a 20% external refuge, qualifies for a five-year registration;"
- "(ii) a product with pyramided PIP toxins (i.e., two or more toxins with distinct, non-cross reacting modes of action), that are non-high dose (the definition for a high dose product remains unchanged), with either a seed blend or external refuge, qualifies for an eight-year registration;"
- "(iii) a product with pyramided PIP toxins (i.e., two or more toxins with distinct, non-cross reacting modes of action), that are high dose, with either a seed blend or external refuge, qualifies for a twelve-year registration;"
- "(iv) a product with pyramided PIP toxins (i.e., two or more toxins with distinct non-cross reacting modes of action), with either a seed blend or external refuge, that has been determined by EPA's science assessment to be 150% as durable as the baseline single toxin product with a 20% external refuge, would qualify for a fifteen-year registration. Products determined by EPA's science assessment to be less than 100% as durable

> as the baseline single toxin product with a 20% external refuge would not qualify for a five-year registration and the registration period for such products will be determined on a case-by-case basis consistent with the level of risk they pose."

In my estimation, it seems logical to predict that registrants will bring more pyramided Bt corn hybrids into the marketplace with increasingly novel proteins. Why? Registrants are more likely to receive longer registration periods for their products saving them valuable resources and producers will come to expect the use of transgenic hybrids with reduced refuge requirements (5%) and preferably those that can be planted as seed mixtures. The broad spectrum of activity afforded by these highly efficacious pyramided Bt hybrids (against many lepidopteran pests and corn rootworms) will reshape our perception of IPM across the Corn Belt.

Soil Insecticide Performance vs. Bt Hybrids

Does the use of a soil insecticide applied at-planting to a non-Bt hybrid still make sense when it comes to effective corn rootworm management? In 2009 (http://bulletin.ipm.illinois.edu/article.php?id=1242) and 2010 (http://bulletin.ipm.illinois.edu/article.php?id=1420), soil insecticides competed very favorably with the Bt corn rootworm hybrids on the basis of root protection in University of Illinois efficacy trials. In 2008 (http://bulletin.ipm.illinois.edu/article.php?id=1038), considerably more variation in root protection was observed across the soil insecticides and Bt rootworm hybrids, especially at DeKalb, where the level of root injury in the checks was intense (nearly 3 nodes of roots destroyed). During the last 2 years, Illinois' producers have witnessed lower corn rootworm pressure than they've typically encountered. Predictably, under these conditions, either the use of a soil insecticide labeled for corn rootworms or a Bt corn rootworm hybrid is likely to offer satisfactory root protection. This does not imply that an insecticidal seed treatment should serve as the stand alone corn rootworm protection product. In most producers' fields, with low to moderate rootworm densities, it seems doubtful that the added protection expenses of both a Bt corn rootworm hybrid and a soil insecticide will offer consistent returns on this investment. However, I have observed instances (DeKalb 2008) when a combined Bt rootworm hybrid and a soil insecticide application significantly reduced root injury over single treatments of products. Again, the level of root pruning in the checks was near a worst case scenario (3 nodes of roots destroyed). Although I have observed this level of root injury in producers' fields, it is not typical.

By regressing yield against the node injury scale (0 to 3) across University of Illinois experiment locations over multiple years, we can begin to see how much variation exists across the corn rootworm protection products and how root injury affects yield (Figure 1). Data for the regression analysis were obtained from DeKalb (2004, 2005, 2007, 2009, and 2010), Monmouth (2005, 2007, and 2009), Perry (2007, 2009, and 2010), and Urbana (2004, 2007, 2009, and 2010). For most corn rootworm products (Bt hybrids and/or soil insecticides), root protection was generally acceptable with less than ½ node of roots pruned. However, insecticidal seed treatments (low rates used on checks) did not provide consistent nor adequate root protection in many of our experiments. The regression analysis revealed that for every one

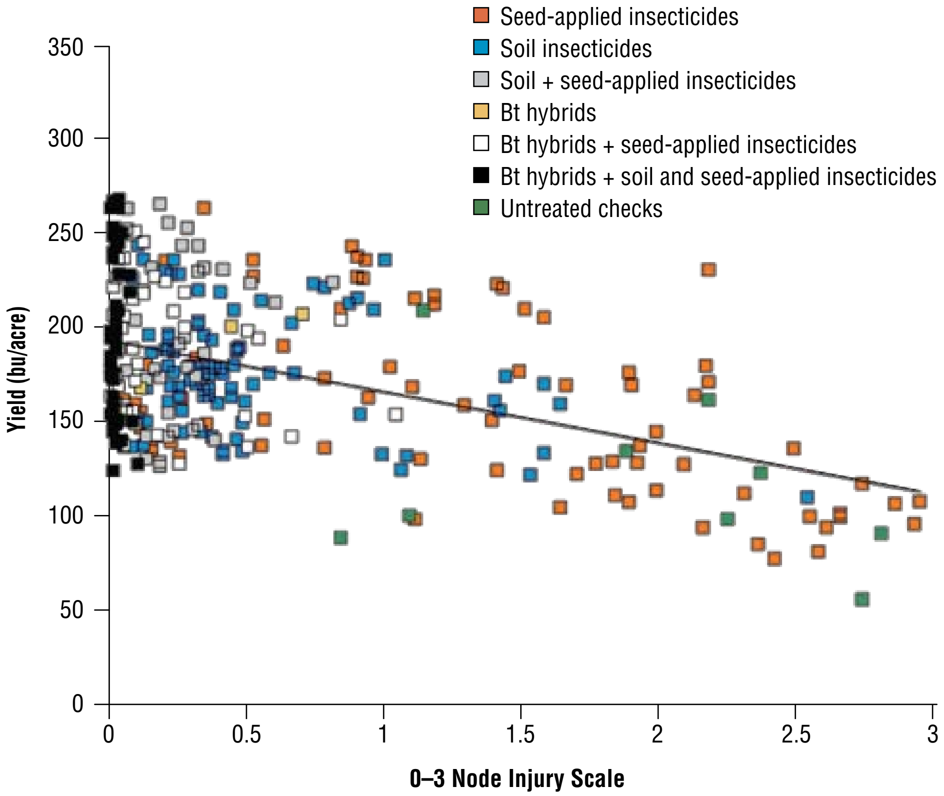


Figure 1 ■ Regression for DeKalb: 04, 05, 07, 09, 10; Monmouth: 05, 07, 09; Perry: 07, 09, 10; Urbana: 04, 07, 09, 10; $n = 324$; $y = -27.2x + 193.8$, $R^2 = 0.22$, F = 90.71, $P < 0.0001$.

node of roots destroyed by corn rootworm larvae, roughly 27 bushels per acre were lost. During hot and dry summers, especially during pollination, severe root pruning could result in even greater yield losses for each node of roots destroyed. This is why I believe more and more producers view annual corn rootworm protection as an insurance investment for their corn crop. This investment when viewed against the overall expenses and risks associated with the production of a profitable corn crop seems warranted. Therefore, don't assume that just because western corn rootworm densities were low across many areas in Illinois during 2009 and 2010, that you can overlook rootworm protection on your farm in 2011. Unfortunately, it's just not that simple.

Future Considerations

In my estimation, it is only a matter of time before the use of seed mixtures (Bt and non-Bt seed) form the foundation of resistance management plans for corn rootworms and lepidopteran insect pests across the Corn Belt of the United States. In addition, I anticipate significant reductions in refuge size (from 20% to 5%) for most Bt hybrids in the Corn Belt. As this approach becomes more and more popular, and Bt usage remains high, it seems likely that areawide suppression will occur for other groups of insect pests similar to that which has now been proven for the European corn borer. Assuming that seed costs trend downward and/or stabilize, insurance pest management for corn insects with pyramided Bt hybrids will become the norm.

Table 1 ■ Registrants, Active Ingredients, Registration Dates, Refuge Requirements, Herbicide Tolerance Information, and Target Insects for Bt Corn Hybrids (list is not all inclusive). Primary source of information US EPA, Office of Pesticide Programs, Biopesticide Registration Action Document (EPA-HQ-OPP-2010-0607-0033, 236 pages), September 30, 2010.

Registrant	Active Ingredients	Original Registration Date	Expiration Date	Refuge Requirement	Herbicide Tolerance	Target Insect Pests*
Dow/Mycogen	Event TC1507, plant optimized Cry1F (Herculex® I)	May 2001	September 30, 2015	Corn Belt—Structured 20% refuge, external fields must be within ½ mile, if within field blocks/strips used, must be at least 4 rows wide.	glufosinate tolerant (LL)	ECB, FAW, BCW, WBC, SWCB
Mycogen Seeds c/o Dow AgroSciences	Event DAS-59122-7, Cry34/35Ab1 (Herculex®RW)	August 31, 2005	September 30, 2015	Corn Belt—Structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glufosinate tolerant (LL)	CRW
Mycogen Seeds c/o Dow AgroSciences	Events DAS-59122-7 + TC1507, Cry34Ab1/Cry35Ab1 + plant optimized Cry1F (Herculex®XTRA)	October 27, 2005	September 30, 2015	Corn Belt—Combined** structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glufosinate tolerant (LL)	ECB, CRW, FAW, BCW, WBC, SWCB
Monsanto	Event MON810, Cry1Ab (YieldGard®CB)	December 1996	September 30, 2015	Corn Belt—Structured 20% refuge, external fields must be within ½ mile, if within field blocks/strips used, must be at least 4 rows wide.	none	ECB
Monsanto	Event MON88017, Cry3Bb1 (YieldGard VT Rootworm/RR2®)	December 13, 2005	September 30, 2015	Corn Belt—Structured 20% refuge (internal blocks, strips), external fields must be adjacent, internal strips at least 4 consecutive rows wide.	glyphosate tolerant (RR2)	CRW
Monsanto	Event MON88017 + MON810, Cry3Bb1 + Cry1Ab (YieldGard VT Triple®)	December 13, 2005	September 30, 2015	Corn Belt—Combined** structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glyphosate tolerant (RR2)	ECB, CRW
Monsanto and DAS LLC (cross-licensing agreement)	SmartStax™ Hybrids (Mycogen or Genuity), Events MON89034 (Cry1A.105 + Cry2Ab2), MON88017 (Cry3Bb1), DAS-59122-7 (Cry34Ab1/Cry35Ab1), TC1507 (Cry1F)	July 20, 2009	November 30, 2011	Corn Belt—Combined** structured 5% refuge for corn rootworm and lepidopteran insects. Refuge must be planted in-field or adjacently to non-Bt hybrids. If non-Bt strips are used within a field, they must be at least 4 consecutive rows wide.	glyphosate (RR2) and glufosinate (LL) tolerant	ECB, CRW, FAW, BCW, WBC, CEW, SWCB
Monsanto	Event MON89034, Cry1A.105 + Cry2Ab2, Genuity® VT Double Pro™ (VT2P)	June 10, 2008	September 30, 2022	Corn Belt—Structured 5%, non-Bt corn and/or non-lepidopteran Bt corn, separate fields (within ½ mile), or blocks within fields, strips must be at least 4 consecutive rows wide.	glyphosate tolerant (RR2)	ECB, FAW, CEW

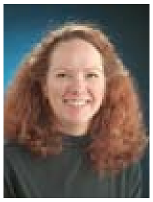
Registrant	Active Ingredients	Original Registration Date	Expiration Date	Refuge Requirement	Herbicide Tolerance	Target Insect Pests*
Monsanto	Event MON89034 + MON 88017, Cry1A.105 + Cry2Ab2+Cry3Bb1, Genuity® VT Triple Pro (VT3P)	June 10, 2008	September 30, 2015	Corn Belt—Combined** refuge (20% structured, adjacent); Separate structured refuges, 5% for corn borer within ½ mile, 20% adjacent field, or internal blocks, strips (at least 4 consecutive rows wide) for corn rootworm.	glyphosate tolerant (RR2)	ECB, CRW, FAW, CEW
Pioneer/DuPont	Event TC1507, plant optimized Cry1F (Herculex I)	May 2001	September 30, 2015	Corn Belt—Structured 20% refuge, within ½ mile, if within field strips used, must be at least 4 rows wide.	glufosinate tolerant (LL)	ECB, FAW, BCW, WBC, SWCB
Pioneer Hi-Bred International, Incorporated	Event DAS-59122-7, Cry34/35Ab1 (Herculex®Rootworm)	August 31, 2005	September 30, 2015	Corn Belt—Structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glufosinate tolerant (LL)	CRW
Pioneer Hi-Bred International, Incorporated	Events DAS-59122-7 + TC1507, Cry34Ab1/Cry35Ab1 + plant optimized Cry1F (Herculex®XTRA)	October 27, 2005	September 30, 2015	Corn Belt—Combined** structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glufosinate tolerant (LL)	ECB, CRW, FAW, BCW, WBC, SWCB
Pioneer/Dupont	Optimum® AcreMax™ 1 (OAM 1) Seed Blend of Herculex XTRA (Cry34Ab1/Cry35Ab1 + Cry1F) + Herculex I (Cry1F)	April 30, 2010	September 30, 2012	Corn rootworm refuge (10%) is blended within each bag of OAM1. Separate 20% structured refuge is required for corn borers in Corn Belt (within ½ mile).	glufosinate tolerant (LL) and glyphosate tolerant (RR2)	ECB, CRW, FAW, BCW, WBC, SWCB
Pioneer/Dupont	Optimum® AcreMax™ RW (OAM RW), seed blend of Herculex RW (Cry34Ab1/Cry35Ab1) + Non-Bt Corn	April 30, 2010	September 30, 2012	Corn rootworm refuge (10%) is blended within each bag of OAM RW.	glyphosate tolerant (RR2)	CRW
Syngenta	Event *Bt*11 with Cry1Ab (AgriSure® CB/LL; field corn)	August 1996	September 30, 2015	Corn Belt—Structured 20% refuge (internal blocks, strips), external field must be within ½ mile, strips must be at least 4 consecutive rows wide.	glufosinate tolerant (LL)	ECB
Syngenta	Event MIR 604, modified Cry3A (Agrisure® RW)	October 3, 2006	September 30, 2015	Corn Belt—Structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	none	CRW
Syngenta	Event MIR604 + Bt11, modified Cry3A + Cry1Ab (Agrisure® CB/LL/RW)	January 24, 2007	September 30, 2015	Corn Belt—Combined** structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glufosinate tolerant (LL)	ECB, CRW

Registrant	Active Ingredients	Original Registration Date	Expiration Date	Refuge Requirement	Herbicide Tolerance	Target Insect Pests*
Syngenta	Event Bt11xMIR162xMIR604, Cry1Ab, Vip3Aa20, mCry3A (Agrisure®Viptera™ 3111)	February 13, 2009	December 31, 2011	Corn Belt—Combined** structured 20% refuge (internal blocks, strips), external field must be adjacent, internal strips at least 4 consecutive rows wide.	glyphosate and glufosinate (LL) tolerant	ECB, SWCB, CEW, FAW, AW, BCW, WBC, CRW
Syngenta	Event Bt11xMIR162, Cry1Ab, Vip3Aa20 (Agrisure®Viptera™3110)	February 13, 2009	December 31, 2011	Corn Belt—Structured 20% refuge (internal blocks, strips), external field must be within ½ mile, strips must be at least 4 consecutive rows wide.	glyphosate and glufosinate (LL) tolerant	ECB, SWCB, CEW, FAW, AW, BCW, WBC

*AW—armyworm, BCW—black cutworm, CEW—corn earworm, CRW—corn rootworm, ECB—European corn borer, FAW—fall armyworm, SWCB—southwestern corn borer, and WBC—western bean cutworm. The target insects listed in this table are not all inclusive.

**For more specific information about establishing separate 20% structured refuges for corn rootworms and lepidopteran pests, consult the appropriate seed product label.

Nematodes that Attack Corn and Soybean: Situation and Management



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The Illinois Corn Nematode Survey

During the growing seasons of 2008, 2009, and 2010, we conducted the most comprehensive assessment of the identities, distribution, and population densities of nematodes in corn in Illinois that has ever been done. Preliminary results from this study were reported during the Corn & Soybean Classics in 2010 and at other meetings since then. Phase I of the study is now complete, and we can report with confidence which nematodes are most likely to occur in corn fields. Comparing these data with established damage threshold values leads us to conclude that a majority of corn fields are at some level of risk for yield loss due to nematodes that parasitize corn. Phase II will involve more detailed analysis of nematode species.

The Illinois Corn Nematode Survey, funded through USDA, was originally proposed by Extension Educators Jim Morrison and Dave Feltes as a pilot project in northern Illinois in 2008. For 2009 and 2010, Jim Morrison expanded the project to include most counties in Illinois. At least 26 cooperators, including Extension Educators, county Directors, and Nematology Lab personnel, participated in the survey. Soil samples, collected as described below, were processed by the Nematology Lab under the direction of Alison Colgrove, Research Specialist. Maps were created from the data by Dennis Bowman, Extension Educator, using ARC-GIS software.

Cooperators who volunteered to collect soil samples were each assigned randomly-generated coordinates along a pre-determined route in one to six counties per cooperator. A total of 587 corn fields in 98 counties were sampled at or near the assigned coordinates from corn plants at the V3 to V6 growth stage. GPS coordinates were recorded for each area sampled. Fields were not assessed for symptoms, and the choice of area to sample in each field was left to the cooperator. Samples comprised 10 to 20 soil cores (2.5-cm-diam) taken to a depth of 25 to 30 cm within the rows. A 100 cm^3 soil subsample was washed through a series of sieves including 20-, 60-, and 400-mesh (850, 250, and 38-µm-apertures, respectively). Material collected on the 20 and 60 mesh sieves was placed on Baermann funnels for 48 hours. Material collected on the 400-mesh sieve was processed by centrifugal flotation for extraction of vermiform nematodes. Data collected from each sample included numbers of nematodes in each of five trophic groups: microbivores (bacterial feeders), fungivores, plant parasites, omnivores, and predators. Plant parasites were identified to morphological group or to genus, and individuals were collected, fixed, and mounted to facilitate species identification.

Total nematode abundance ranged from 66 to 7,938/100 cm^3 soil, composed of about 50% bacterivores and 50% plant parasites; very few fungivores, omnivores, or predators were observed. This type of nematode community structure is thought to reflect an “unhealthy” situation because there is a high level of parasitism occurring, relative to the level of nutrient cycling reflected by the bacterial feeding nematodes.

Densities and distributions of corn nematodes in Illinois

The most common group of plant-feeding nematodes is called the “tylenchids,” a group whose effects on plant growth and yield is mostly unknown, but some of them (e.g., *Ditylenchus* spp. and *Tylenchus* spp.) are known to be damaging on some hosts. Others are thought to be fungal-

Table 1 ■ Distribution and population densities (numbers of nematodes per 100 cm^3 soil) of common plant-parasitic nematodes in Illinois in 2010. "Frequency" is the percentage of samples (of 587) in which each nematode genus was found. Threshold values for moderate and severe risk of injury or yield loss were established for Illinois by Dale Edwards, USDA-ARS (retired). Mean, median, and maximum values were computed across samples with one or more of the indicated nematodes.

Statistic	Spiral	Lesion	Stunt	Lance	Pin
Frequency	99%	84%	37%	22%	23%
Threshold (moderate)	151	26	51	41	101
Threshold (severe)	301	51	101	76	501
Mean	167	38	38	21	35
Median	111	24	18	12	12
Maximum	1,404	252	498	174	510

feeders, or possibly able to feed on both plants and fungi. Genera and species of animals in this group were not determined, but they were counted as plant parasites rather than fungivores. They were observed in 99% of the samples, ranging in population densities from 6 to 948/100 cm^3 soil.

The second most frequent (98.5%) group was the spiral nematode complex, consisting mostly of *Helicotylenchus* species. These nematodes were found most commonly in central and northern Illinois (Fig. 1). Certain species

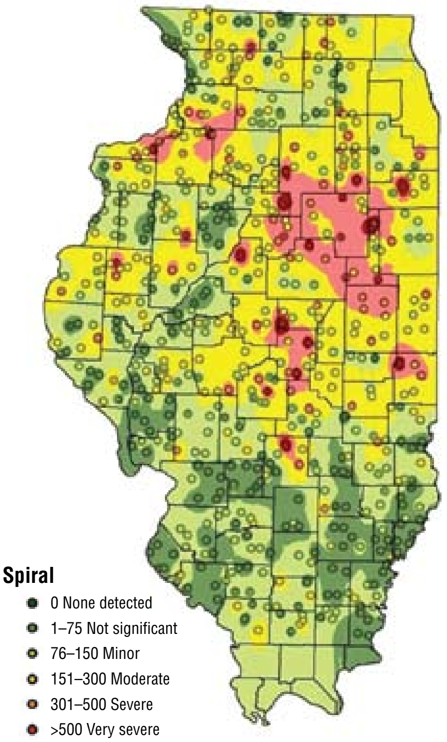

Figure 1 ■ Map of the distribution of spiral nematodes in Illinois 2009-2010. Each dot represents one soil sample. Dot color indicates the level of risk of injury or yield loss due to spiral nematodes according to threshold values established for Illinois by Dale Edwards, USDA-ARS (retired). Map prepared by Dennis Bowman, University of Illinois.

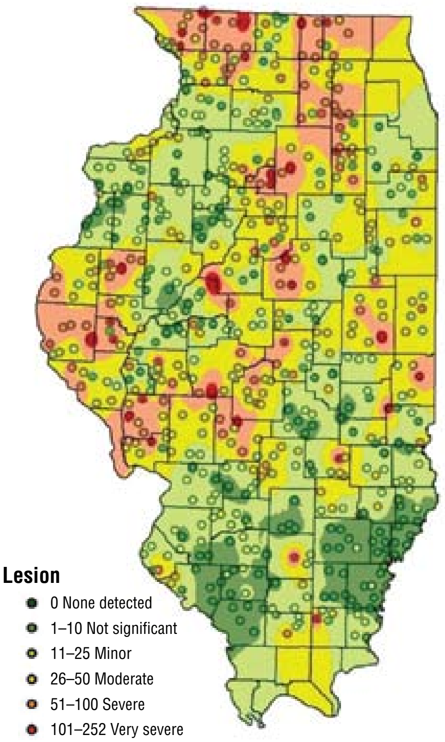

Figure 2 ■ Map of the distribution of lesion nematodes in Illinois 2009-2010. Each dot represents one soil sample. Dot color indicates the level of risk of injury or yield loss due to lesion nematodes according to threshold values established for Illinois by Dale Edwards, USDA-ARS (retired). Map prepared by Dennis Bowman, University of Illinois.

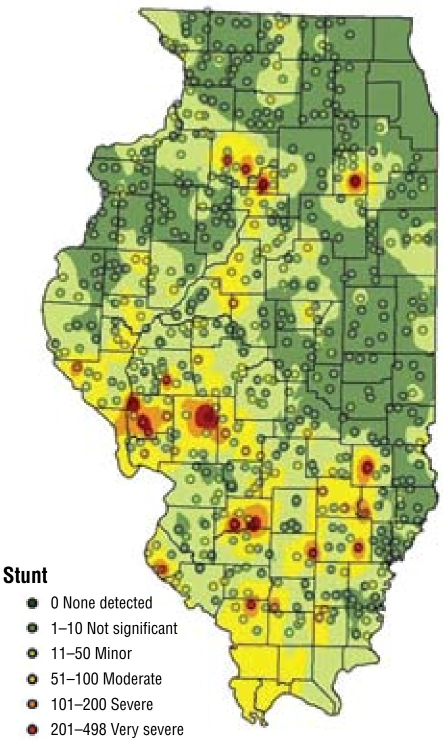

Figure 3 ■ Map of the distribution of stunt nematodes in Illinois 2009-2010. Each dot represents one soil sample. Dot color indicates the level of risk of injury or yield loss due to stunt nematodes according to threshold values established for Illinois by Dale Edwards, USDA-ARS (retired). Map prepared by Dennis Bowman, University of Illinois.

of spiral nematodes can be pathogenic, but fairly high numbers of nematodes are required (Table 1).

Many species of lesion or root-lesion nematodes, *Pratylenchus* species, are known to be pathogenic to corn. Lesion nematodes were found in 84% of the samples (Table 1), and the population densities indicated that at least 2/3 of the fields were at moderate to severe risk of injury or yield loss (Fig. 2). Molecular analysis was used to identify at least five different *Pratylenchus* species: *P. crenatus*, *P. hexincisus*, *P. neglectus*, *P. penetrans,* and *P. scribneri.* All but one of these has been reported as a pathogen of corn. Work is continuing to verify the numbers of each species.

Stunt nematodes were found in 37% of the samples (Table 1). There were at least three different species in two genera observed, all of which are known parasites of corn. The areas most at risk for injury due to stunt nematodes are in the southern and western parts of Illinois (Fig. 3).

Other genera of potential corn pathogens were observed (Table 1). In addition, dagger, needle, ring, root-knot, sting, and stubby-root nematodes were observed occasionally, but many of these are associated with sandy soils, which tended to be underrepresented in our samples. Juveniles of *Heterodera* (cyst nematodes) were observed in 57% of the samples, but these were unlikely to be corn parasites. Species identification will provide additional insight into the potential for any or all of these groups or genera to reduce corn growth or yield.

Seed treatment tests 2010

Several companies are currently developing seed treatment products for soybean and corn nematode management. We evaluated experimental and labeled products for their effects on nematode populations, and on crop growth and yield. Soybean tests were conducted in two locations, both infested with soybean cyst nematode (SCN). The Monmouth site had low numbers of SCN (209 eggs/100 cm^3 soil) and the Urbana site had a moderate infestation (545 eggs/100 cm^3 soil). Corn tests were conducted in two locations as well, near Topeka and Arenzville, both near Havana, IL. The Topeka site had moderate to severe levels of lance nematodes, low to moderate levels of lesion nematodes (tentatively identified as *P. alleni*), and varying levels of spiral, dagger, stubby-root, ring, needle, and foliar nematodes. The Arenzville site had moderate to severe levels of stunt nematodes (a *Tylenchorhynchus* species) and varying levels of spiral, lesion, lance, dagger, stubby root, and needle nematodes. All seed for both soybean and corn tests were treated by the companies represented in the tests, and all tests were conducted in small plots with four to six replications depending on the plot size. All plots were evaluated for stand and vigor early in the season. Soybean plots were sampled at planting, mid-season, and harvest for SCN egg counts, and corn plots were sampled at about 4 weeks after planting for extraction of nematodes from soil and roots. Yields were collected at harvest maturity (Figs. 4-7). Differences among treatments will be discussed.

Summary

Plant-parasitic nematodes are common in corn, and the population densities of some species indicate a moderate to high risk of yield loss in many corn fields. SCN is present in over 80% of the soybean fields, and is known to reduce soybean yields relative to the number of eggs present at planting. New nematode management products, unlike the older chemistries, are intended to suppress nematode populations early in the season, which is the critical

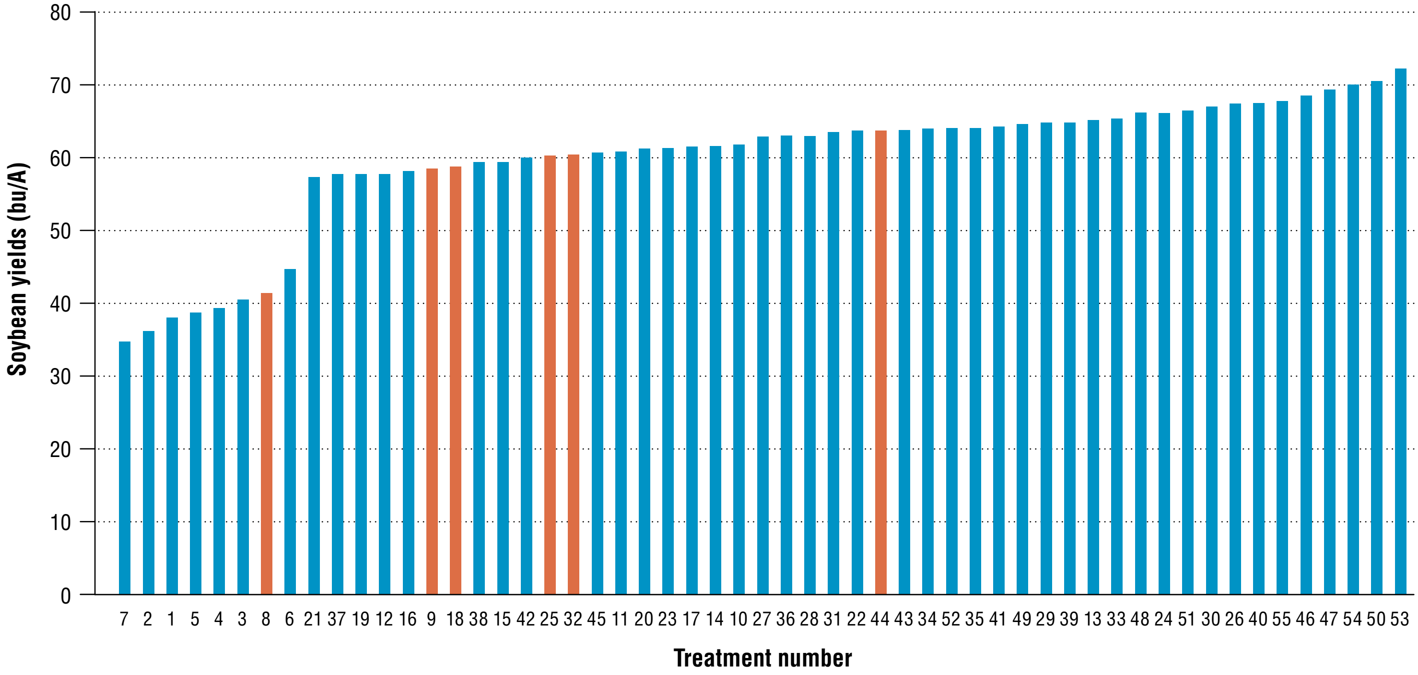

Figure 4 ■ Soybean yields as affected by 55 soybean seed treatments in field plots conducted at the Northwestern Illinois Agricultural Research and Demonstration Center in Monmouth, IL, by Eric Adee, Superintendent. The average population density of SCN eggs at planting was 209/100 cm^3 soil (SCN Type 2). Bars representing nontreated checks are orange (treatment numbers 8, 9, 18, 25, 32, and 44). Treatments 1-8 were not glyphosate resistant, and were accidentally sprayed with glyphosate early in the season; they recovered, but produced poor yields compared with the other treatments.

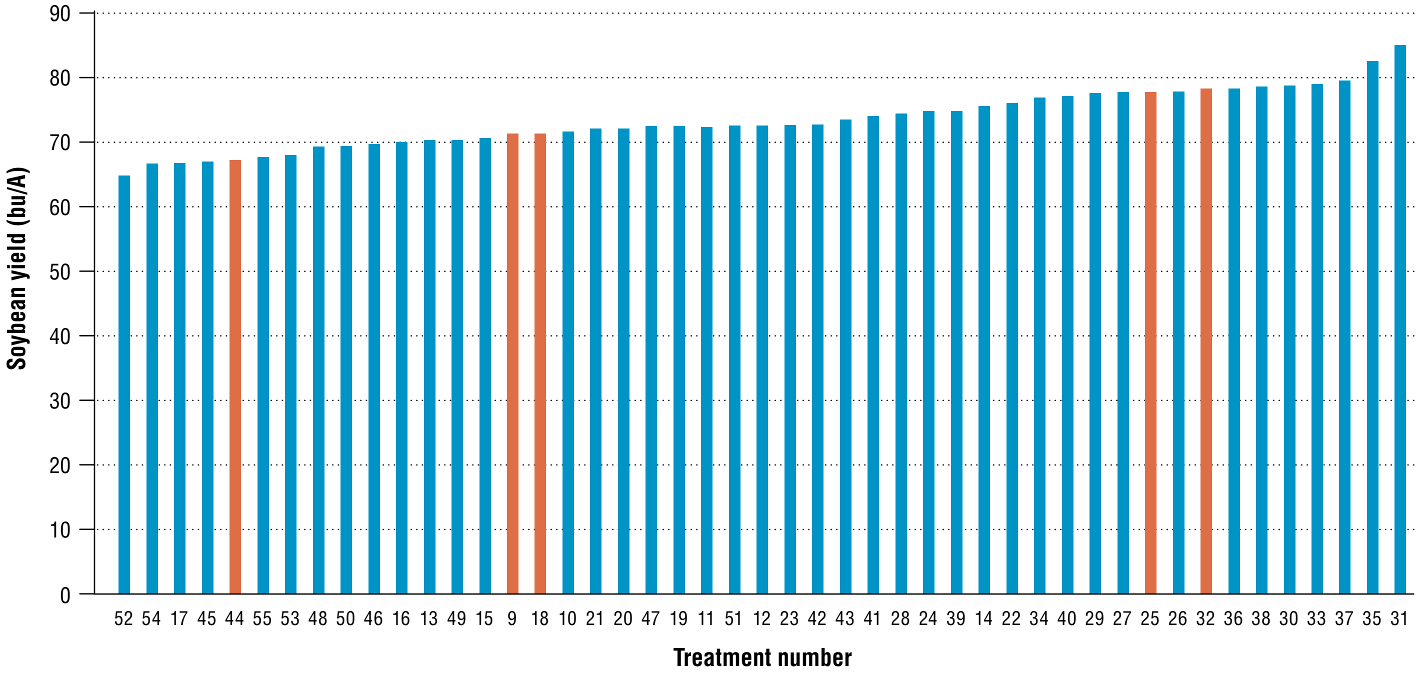

Figure 5 ■ Soybean yields as affected by 47 soybean seed treatments in field plots conducted at the South Farm in Urbana, IL, by Alison Colgrove and Keith Ames. The average population density of SCN eggs at planting was 545/100 cm^3 soil (SCN Type 2). Bars representing nontreated checks are orange (treatment numbers 9, 18, 25, 32, and 44). Treatments 1-8 were not glyphosate resistant, and did not recover from accidentally applied glyphosate early in the season.

time for nematode effects on yields. A number of companies are developing corn and soybean nematode management products. Some of these products provided a yield advantage in fields with moderate to high risk of yield loss due to nematodes.

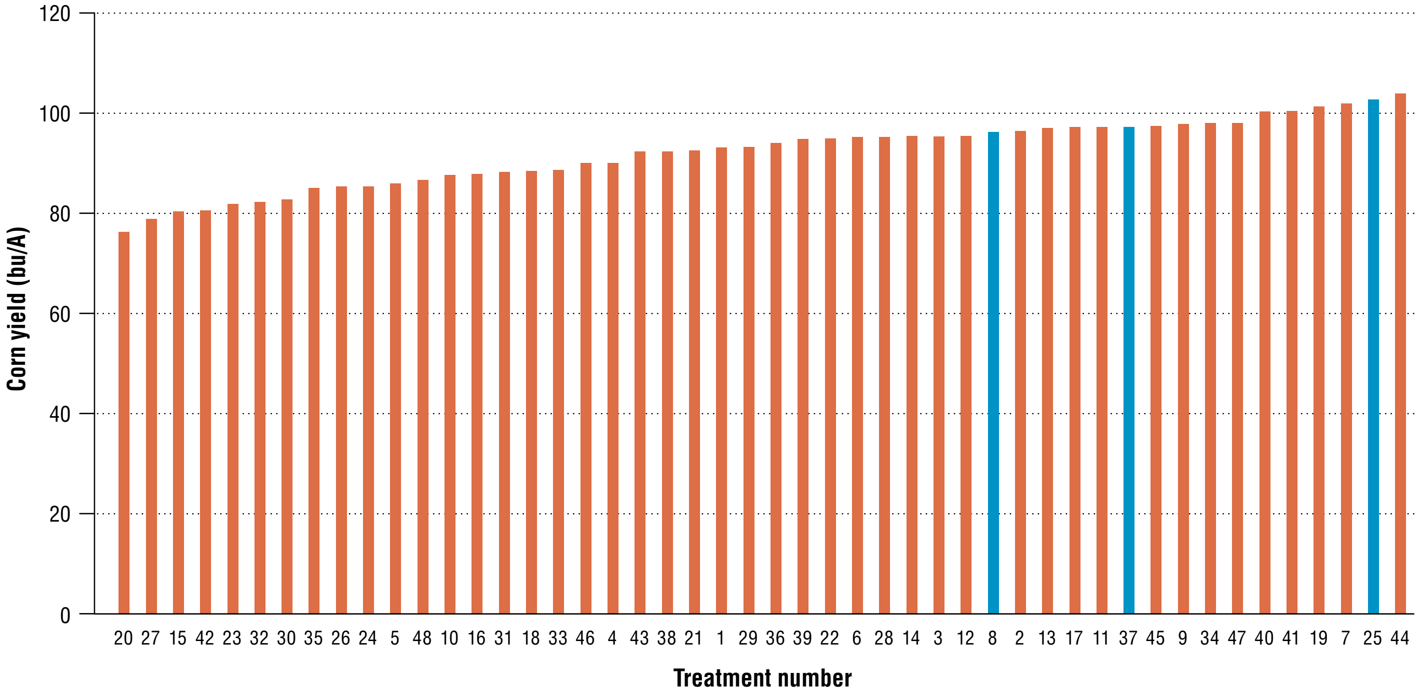

Figure 6 ■ Corn yields as affected by 48 corn seed treatments in field plots conducted on-farm near Topeka, IL, by Alison Colgrove and Keith Ames with the help of Matt Montgomery, Extension Educator. The predominant corn pathogen in the field was lance nematode, with varying levels of spiral, lesion, lance, dagger, stubby root, and needle nematodes. Bars representing nontreated checks are blue (treatment numbers 8, 25, 37).

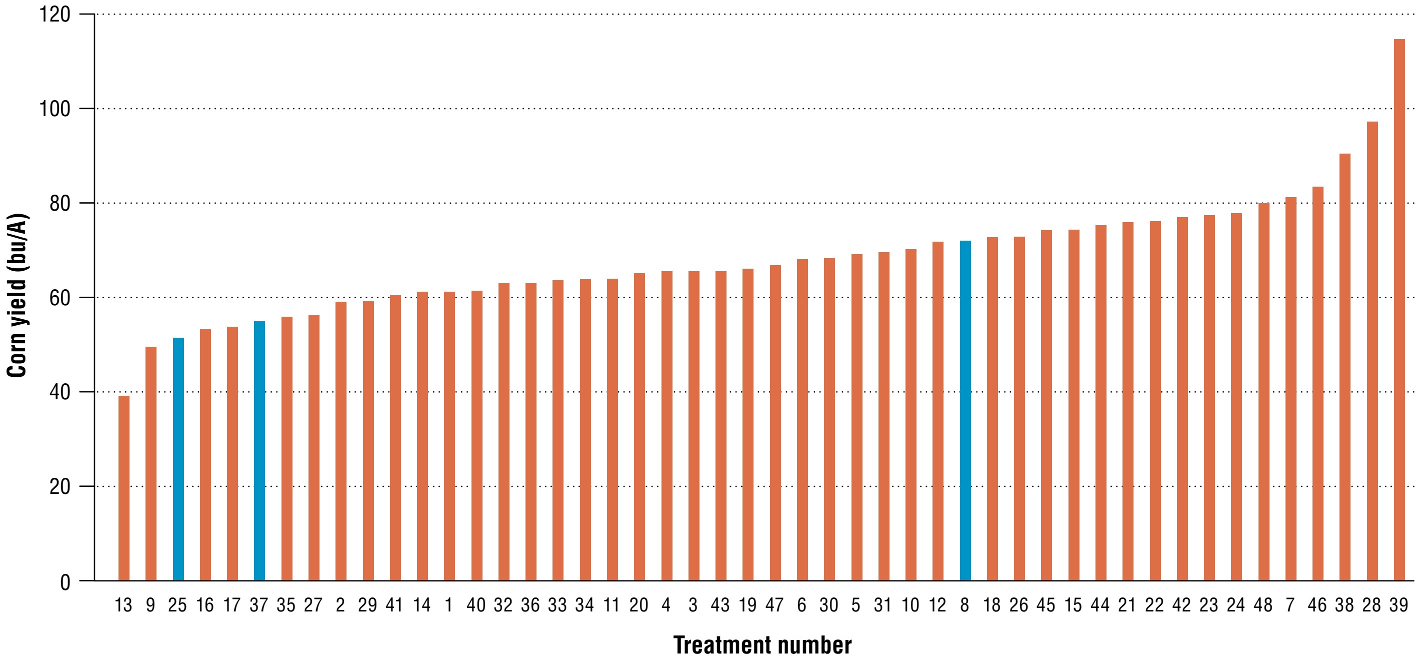

Figure 7 ■ Corn yields as affected by 48 corn seed treatments in field plots conducted on-farm near Arenzville, IL, by Alison Colgrove and Keith Ames with the help of Matt Montgomery, Extension Educator. The predominant corn-pathogen in the field was stunt nematode, with varying levels of spiral, lesion, lance, dagger, stubby root, and needle nematodes. Bars representing nontreated checks are blue (treatment numbers 8, 25, 37).

Improved Nitrogen Management Through Source, Placement and Timing

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Proper nitrogen (N) management is fundamental for sustainable corn (*Zea mays* L.) production both in terms of environmental quality and profitability. Nitrogen fertilizer is an expensive input in corn production, but it is critical since this crop is, in general, very responsive to N fertilizer. Nitrogen is a sort of "double-edge sword." On one hand, applying less N than what will be needed by the crop can result in reduced yield and profits. On the other hand, over applying N typically does not cause a yield reduction, but can result in environmental degradation and lower profit. Although very important, it will not be the focus of this proceedings paper to discuss how to determine what the proper N rate should be, since this is a topic in and of itself and was covered in previous years during the conference. Once the appropriate N rate has been determined, ensuring that the applied N remains in plant-available form when the plant needs it, is just as important as knowing how much N to apply. However, this is not an easy task since N can be leached out of the root zone, volatilize, denitrify, or become immobilized into organic compounds. While some of the factors that impact plant N availability may be out of our control (i.e., weather), there are management strategies we can use to try to maximize N availability. The objective of this proceedings article is to discuss recent findings on management related to N sources, placement method, and timing of application. While I will present a separate brief discussion on each of these three variables, most often effective N management requires a combination of these variables.

Nitrogen Source

There are many N sources available for corn production. The most widely used N sources by farmers in Illinois are first, anhydrous ammonia; second, urea-ammonium nitrate (UAN); and third, urea. All these are excellent sources and can meet corn N needs if managed correctly. In addition there are nitrification inhibitors, urease inhibitors, and coatings that can be used along with these N sources to protect N from loss or from becoming unavailable for crop uptake. However, it is important to realize that the benefits of using these technologies can vary with rate of N application, soil condition, type of soil, time of year, geographic location, and overall weather conditions between the time of N application and crop uptake. Once ammonium (NH_4^+) is nitrified to nitrate (NO_3^-), N is susceptible to loss by denitrification or leaching. Nitrification inhibitors such as dicyandiamide (DCD) or nitrapyrin (N-Serve) have been commercially available for several decades now. Research has shown that combining the inhibitor with anhydrous ammonia can slowdown nitrification and reduces the potential for N loss. Recently, a new formulation of nitrapyrin from Dow AgroSciences with the trade name "Instinct^{TM}" has become available for spring-applied UAN and for liquid manure. Over the last few years in Illinois (eight site-years), we have tested pre-plant applications of UAN and UAN with Instinct^{TM} applied at the rate of 35 oz acre^{-1} and incorporated in the soil within few days of application. Our preliminary testing has shown no yield benefit with the use of Instinct^{TM} compared to UAN (Figure 1). While there was a significant yield increase with N rate, the N source by rate interaction was not significant, indicating that the response to Instinct^{TM} and UAN was similar across all N rates.

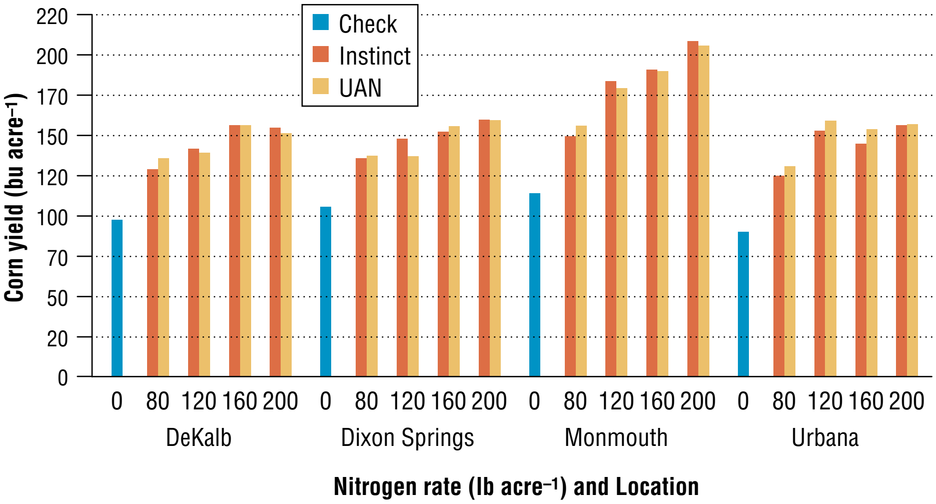

Figure 1 ■ Corn yield response to UAN or UAN with the nitrification inhibitor Instinct™ at different spring pre-plant nitrogen fertilization rates for DeKalb (mean of two years), Dixon Springs (one year), Monmouth (mean of two years), and Urbana (mean of three years).

Ammonia volatilization losses from urea can occur by chemical processes and when urease enzymes hydrolyze (breakdown) urea-containing fertilizers into ammonia (NH_3). It is possible to reduce volatilization losses from urea by using a urease inhibitor, such as N-(n-butyl) thiophosphoric triamide (known as NBPT or Agrotain). Some products, such as SuperU®, use a combination of both a nitrification inhibitor and a urease inhibitor. Another alternative to chemical inhibitors is the use of physical barriers to protect N from being transformed to forms that can be lost. Polymer coating of urea has been a relatively new development in the fertilizer industry. While polymer coated urea can reduce volatilization, incorporation by tillage is recommended. We have observed in some of our research trials that the coating makes urea temporarily impermeable to water. This can cause the granule to float away as water flows on the soil surface (Figure 2).

Figure 2 ■ Broadcast-applied polymer coated urea floated to the end of the field in moving water.

Method of Nitrogen Placement

Proper nitrogen management includes correct placement method for the different N sources. Urea and urea containing fertilizers are normally better protected from loss by being incorporated in the soil either by tillage or rain. The content of urease enzyme is normally much higher in the soil surface (especially where there is high residue cover) than within a shallow depth from the surface. In addition, once urea is incorporated in the soil if there is some ammonia formation, it is very unlikely for that ammonia to escape to the atmosphere.

With anhydrous ammonia, volatilization losses occur most often during—or soon after—application when the application is not fully retained in the soil by organic matter and soil water. Because anhydrous ammonia moves out into the soil until it is all dissolved in soil water, it is lost more easily from shallow placement than is ammonia in a low-pressure solution, which is already dissolved when applied. Nevertheless, low-pressure solutions contain some free ammonia and thus need to be placed into the soil at a depth of 2 to 4 inches. Whenever there is a direct opening from the point of injection to the soil surface, some ammonia will escape to the atmosphere; thus, it is important to apply into soil conditions that allow full closure of the applicator knife track.

Anhydrous ammonia is normally injected at 6–8 inches below the soil surface for fine-textured soils and 8–10 inches in coarse-textured soils. Recently, a new high speed low draft applicator (HSLD), most commonly known as John Deere 2510H, was developed to inject anhydrous ammonia at shallow depth with minimal soil disturbance. Some of the potential benefit of this applicator are that it allows for faster speed of application, less horsepower requirements, and low disturbance of soil. We compared this new system to a traditional anhydrous ammonia mole-knife injection applicator (TRAD) on a three-year study at three locations with soybean as the previous crop. I conducted the study in Illinois, Dr. John Sawyer in Iowa, and Dr. Dave Mengel in Kansas. We applied anhydrous ammonia at 7 inch depth and 6 miles hr^{-1} with the TRAD, and 4 inches and 8 to 10 miles hr^{-1} with the HSLD. Applications were done under the future corn-row for fall and spring pre-plant applications and between every other row for sidedress (around V4 development stage).

We observed that while the HSLD allows faster speed of application and less horsepower requirements, the shallow depth of injection could cause yield loss when soil conditions are not near ideal for the application. For example, in Illinois fall soil conditions were slightly wet for one of the years of the study and caused N loss relative to the TRAD as measured by corn yield (Figure 3). On the other hand, when soil conditions were

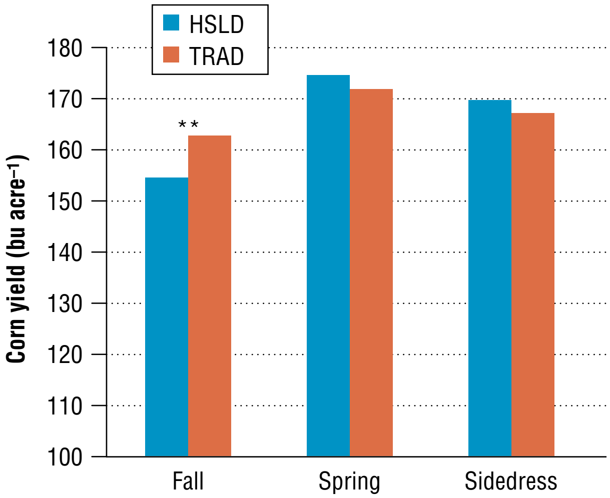

Figure 3 ■ Corn yield in Champaign County averaged over three years (2007-2009) as impacted by time of application (fall, spring pre-plant, and sidedress at V4 development stage) and anhydrous ammonia application system [high speed low draft applicator (HSLD) and traditional anhydrous ammonia mole-knife injection applicator (TRAD)]. **Indicate treatment difference for the specific set of bars at $P<0.05$.

adequate, both applicators performed similarly for the spring and sidedress times. Across all site-years, we observed that the TRAD allowed higher rates of application without N loss compared with the HSLD. While N losses from the highest rate of application produced a significant yield reduction (Figure 4), the lower yield was not related to insufficient nitrogen availability since the application rate was above the averaged economical optimum N rate of 145 lb acre^{-1}. The drop in yield was the result of seedling injury for the spring pre-plant application for two of the years in Iowa and canopy damage by ammonia losses during sidedress application in Kansas. Thus, while the HSLD provides an alternative to the TRAD, the new applicator is not as "forgiving" if the application is done when soil conditions are not near ideal. Additionally, applications should not be done near the seed-row, and high N rates should be avoided when applications are done on every other row.

Timing of Nitrogen Application

In general, the longer the period between N application and absorption by the crop, the greater the chance that N will not be available for the crop. That said, normally there is no difference in the economical optimum yield or the amount of N needed to achieve that yield between pre-plant and sidedress N application; but these timings in general produce greater yield with less N (greater N efficiency) than fall applications (Figure 5). However, fall applications are often less expensive because they require less transportation and storage. They also provide logistical advantages such as generally better soil physical conditions in the fall to protect soils from compaction during fertilizer application, saving time in the spring and allowing early planting, and better distribution of labor and equipment. Since the loss potential of N

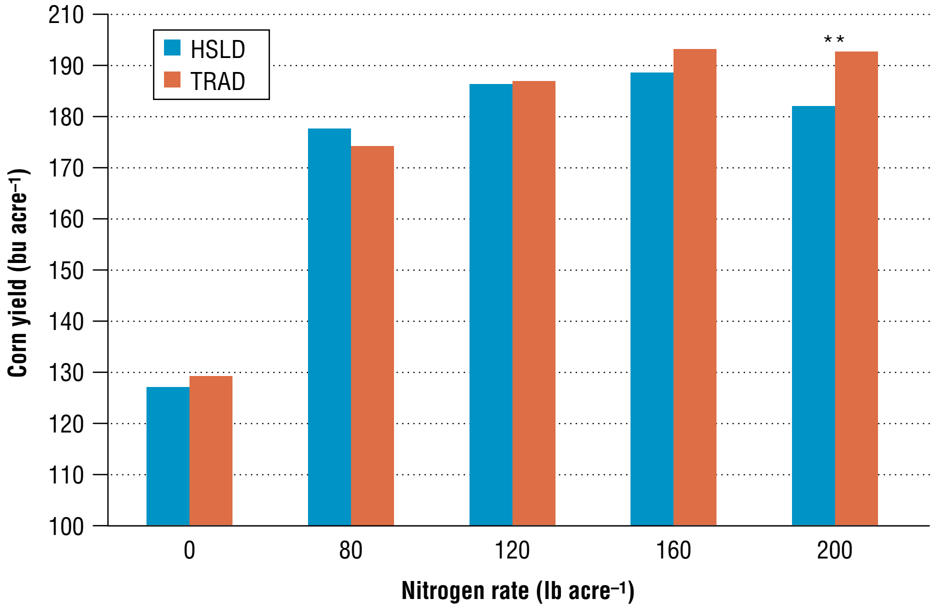

Figure 4 ■ Corn yield averaged over three years (2007–2009) and three locations (Illinois, Iowa, and Kansas) as impacted by nitrogen rate and anhydrous ammonia application system [high speed low draft applicator (HSLD) and traditional anhydrous ammonia mole-knife injection applicator (TRAD)]. **Indicate treatment difference for the specific set of bars at $P<0.05$.

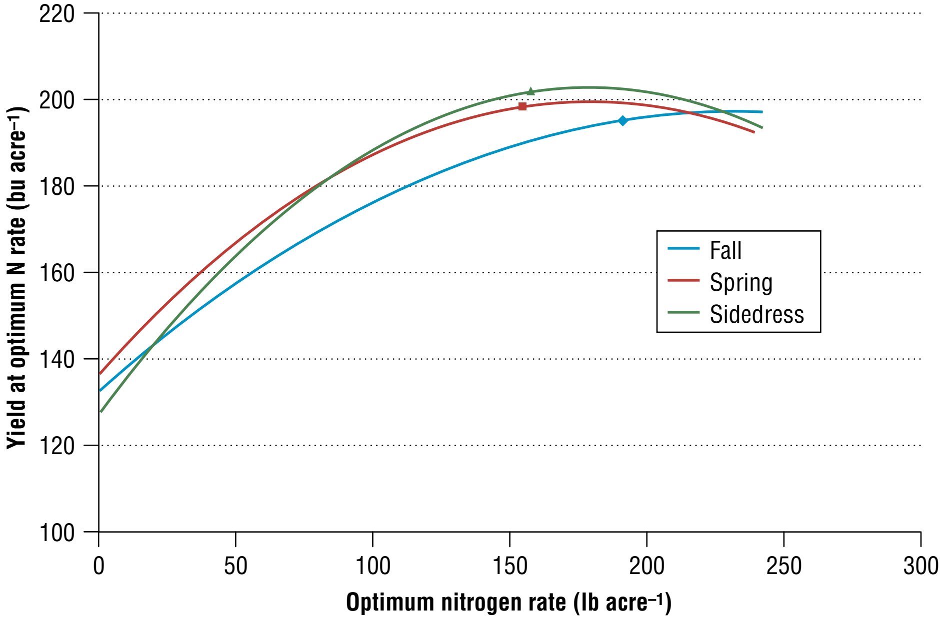

Figure 5 ■ Corn response to nitrogen rate averaged over a two-year period (2008–2009) as impacted by time of application. Symbols represent optimum points calculated at a 0.1 nitrogen price: corn price ratio.

is often greater with fall applications, measures should be taken to minimize such losses. Fall applications should be done only in soils and regions where potential for N loss are low. Fall N applications should not be done in soils that are sandy, organic, very poorly drained or excessively drained, or in regions where soils rarely freeze or the time elapse between 50 °F and soil freezing is too long. For Illinois, fall N applications for corn should not be done in any soil south of a line that approximates Route 16. As mentioned above, nitrification inhibitors can help reduce the potential for loss. However, the length of time that inhibitors remain effective in the soil also depends partly on soil temperature since warmer temperatures breakdown nitrification inhibitors more quickly. Nitrification inhibitors are normally most effective for fall applications or in wet springs for pre-plant applications. We conducted a study in Champaign County during 2009-2010 with fall and spring pre-plant applications of anhydrous ammonia with a nitrification inhibitor (N-Serve) (AA+) and without the inhibitor (AA). The inhibitor produced 7 and 9 bu acre^{-1} greater yield compared with the same application without the inhibitor for fall and spring pre-plant applications, respectively (Figure 6). While the inhibitor was as effective for fall and spring application, N loss due to prolonged wet conditions in the spring caused an overall 54 bu acre^{-1} drop in yield for the fall application relative to the spring application. This illustrates the potential for N loss when N is applied long before planting and spring conditions turn excessively wet. A significant N source by N rate interaction indicated that the inhibitor was most effective for the low N rate (80 lb acre^{-1}). For both fall and spring applications, N-serve resulted in a 21 bu acre^{-1} yield increase compared to when the inhibitor was not used.

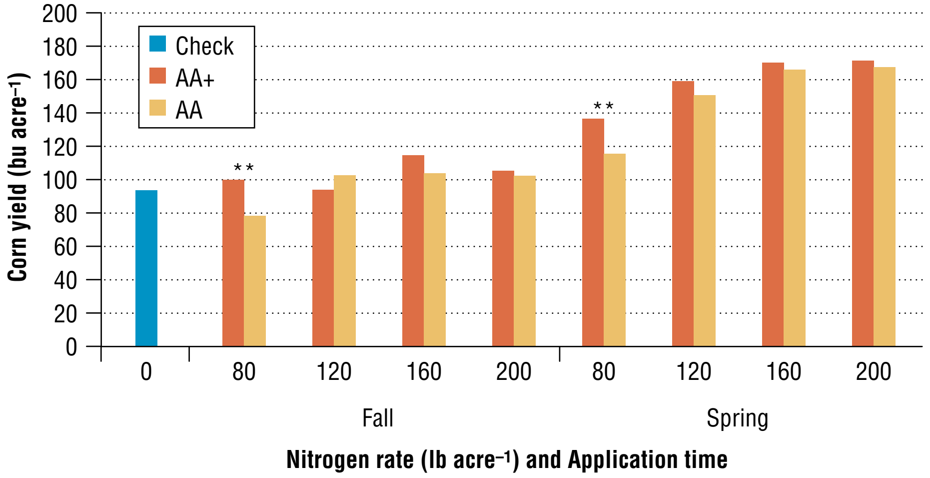

Figure 6 ■ Corn yield averaged over two years (2009–2010) in Champaign County comparing anhydrous ammonia applied with the nitrification inhibitor N-Serve (AA+) or without the inhibitor (AA) for various nitrogen fertilizer rates applied in the fall or in the spring (pre-plant). **Indicate treatment difference for the specific set of bars at $P<0.05$.

Revisiting the Realm of Residuals

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Extension weed scientists across much of the United States have expended considerable time and effort exhorting the benefits and advantages of integrating multiple weed management tactics, including the use of soil-residual herbicides, into glyphosate-resistant corn and soybean production systems. Two advantages of utilizing soil-residual herbicides include reducing early-season weed interference that can lead to loss of crop yield (Figure 1), and reducing the intensity of selection for herbicide-resistant weed populations. Other benefits, including enhanced control of volunteer glyphosate-resistant corn in soybean and improved efficacy against weed species less sensitive to glyphosate, can be realized by integrating soil-residual herbicides and/or tankmix partners in glyphosate-resistant cropping systems.

Recent evidence suggests weed management practitioners are in fact moving toward a more integrated weed management program in glyphosate-resistant soybean. During the 2009 and 2010 University of Illinois Corn & Soybean Classics, attendees were asked a series of survey questions related to a variety of agronomic topics. Two weed science-related questions were posed, with data gathered using the Turning Point response system. The first question, with the four possible options from which attendees could select, was:

"If you grow glyphosate-resistant soybean, which of the following scenarios best describes the number of different herbicides you use to control weeds?"

a. Glyphosate only
b. A tankmix partner with glyphosate
c. A soil residual followed by glyphosate
d. A soil residual followed by glyphosate and a tankmix partner

Across all locations, 1332 responses to this question were collected. Before actually posing the question and collecting the survey responses we (admittedly) supposed the "glyphosate-only" option would attain a very high

Figure 1 ■ Reduction of corn yield potential caused by early-season weed interference can occur before postemergence herbicides are applied.

percentage of responses, but were (pleasantly) surprised when only 24% of the responses were tallied for the "glyphosate only" option. The percentage of participants indicating "glyphosate only" tended to be higher in the more northern areas of the state. While we have no comparable "historical" data against which to compare these data, national-level surveys conducted after the first year glyphosate-resistant soybean were commercially available indicated 8 out of 10 farmers did not use soil-residual herbicides in their weed management programs in glyphosate-resistant soybean.

Additionally, the issue of glyphosate resistance in weeds appears to be on the minds of weed management practitioners. The second question to the 2009 audiences, with the three possible options from which attendees could select, was:

"Do you believe glyphosate-resistant weeds will change the way you manage weeds in glyphosate-resistant cropping systems within the next 5 years?

a. Yes
b. No
c. Don't know

Across all locations, 877 responses to this question were collected. An overwhelming percentage of respondents, 91%, indicated they believed glyphosate-resistant weeds will change the way they manage weeds in glyphosate-resistant cropping systems within the next 5 years.

We believe these data are indicative that the fallacy of glyphosate alone being able to resolve all weed problems in corn and soybean is becoming increasingly obvious. The dynamic and adaptable nature of weeds has (again) demonstrated how difficult it can be to adequately manage weeds long-term with a singular approach.

These data also suggest that soil-applied herbicides are likely to be utilized more frequently in future growing seasons. These herbicides are an important part of weed management programs in corn and soybean production systems. Early preplant (EPP), preplant incorporated (PPI), and preemergence (PRE) surface are the most common types of herbicide applications to soil. EPP applications are typically made several weeks prior to planting and are more common in corn than soybean fields. PPI applications were once very common, but have declined in recent years with the adoption of conservation tillage systems. PRE applications are generally made within one week of crop planting. Regardless of when or how a herbicide is applied to the soil, the effectiveness of soil-applied herbicides is influenced by several factors.

In order for a soil-applied herbicide to be effective, the herbicide needs to be available for uptake by the weed seedling (usually before the seedling emerges, but some soil-applied herbicides can control small emerged weeds under certain conditions). Processes such as herbicide adsorption to soil colloids or organic matter can reduce the amount of herbicide available for weed absorption. Soil-applied herbicides do not prevent weed seed germination; rather, they are first absorbed by the root or shoot of the seedling and then exert their phytotoxic effect. Generally, this happens before the seedling emerges from the soil. For a herbicide to be absorbed by weed seedlings, the herbicide must be in the soil solution or vapor phase (i.e., an available form). How is this achieved? The most common methods for herbicides to become dissolved into the soil solution are by mechanical incorporation or precipitation. EPP applications in no-till systems attempt to increase the likelihood that sufficient precipitation will be received before planting to incorporate the herbicide. If, however, no precipitation is received between application and planting, mechanical incorporation (where feasible) will, in most instances, adequately move the herbicide into the soil solution. Herbicide that remains on a dry soil surface following application may not provide much effective weed control and is subject to various dissipation processes, some of which are described in subsequent paragraphs.

Many weed species, in particular small-seeded species, germinate from fairly shallow depths in the soil. The top one to two inches of soil is the primary zone of weed seed germination and should thus be the target area for herbicide placement. Shallow incorporation can be achieved by mechanical methods or precipitation. Which of these two methods is more consistent? Precipitation provides for a fairly uniform incorporation, but mechanical incorporation reduces the absolute dependence on receiving timely precipitation. How much precipitation is needed and how soon after application the precipitation should be received for optimal herbicide performance depends upon many factors, but generally one-half to one inch of precipitation within 7 to 10 days after application is sufficient.

Herbicides remaining on the soil surface, or those placed too deeply in the soil, may not be intercepted by the emerging weed seedlings. Herbicides on the soil surface are subjected to several processes that reduce their availability. Volatility (the change from a liquid to gaseous state) and photolysis (degradation due to absorption of sunlight) are two common processes that can reduce the availability of herbicides remaining on the soil surface. Volatility potential is determined by several soil properties and properties of the herbicide formulation, while photolysis is primarily dependent on herbicide properties.

Dry soil conditions are conducive for planting, but may also reduce the effectiveness of soil-applied herbicides. If herbicide applications are made prior to planting and no precipitation is received between application and planting, a shallow mechanical incorporation prior to planting may help preserve much of the herbicide's effectiveness.

Another Reason to Integrate Weed Management Programs: A Novel Type of Herbicide Resistance

Additional evidence that soil-applied herbicide will (again) become important components of integrated weed management programs is gained by the discovery of a novel type of herbicide resistance. Weed scientists at the University of Illinois are currently working with a type of herbicide resistance that has not previously been reported. Basic and applied research is underway with an Illinois waterhemp population that is resistant to herbicides that inhibit 4-hydroxyphenyl pyruvate dioxygenase, generally referred to as HPPD-inhibiting herbicides. Foliar-applied HPPD inhibitors are commonly used for control of annual broadleaf and grass weed species in corn. Several active ingredients from this herbicide family are commercially available, including tembotrione, topramezone and mesotrione. These active ingredients are available either as individual products (Laudis, Impact, and Callisto, for example) or as components of premixtures.

This biotype was discovered during August 2009 in a McLean County field dedicated to seed corn production for the previous six years. During that same period, the field was treated with multiple applications of herbicides that inhibit HPPD. In 2009, control of this waterhemp biotype was poor following a foliar application of tembotrione (Laudis). During late summer 2009, inflorescences were collected from female waterhemp plants that were not controlled following a foliar application of tembotrione. Seeds from these females were used to generate plants for the greenhouse experiments described herein.

In the greenhouse, uniformly-sized waterhemp plants (4–5 inches tall) were treated with one of three HPPD-inhibiting herbicides, atrazine alone, or a tank-mix combination of HPPD-inhibitor and atrazine. The HPPD inhibitors and their respective application rates included Impact at 0.75 fl oz/acre, Laudis at 3 fl oz/acre and Callisto at 3 fl oz/acre. Atrazine, alone or in combination with an HPPD inhibitor, was applied at 0.5 lb ai/acre. Initial greenhouse experiments confirmed anecdotal reports from the field. Plants grown from field-collected seed and treated with these HPPD-inhibiting herbicides survived, whereas treated plants from two known sensitive populations (used for comparison) were completely controlled (Table 1). Tank-mixing atrazine with each HPPD inhibitor improved control of the resistant population over that provided by each HPPD herbicide alone, but survival was still much greater than with the sensitive controls.

Field research conducted in 2010 has confirmed the greenhouse results. Under field conditions, control of this population 14 days after postemergence application of commercial rates of Callisto, Laudis or Impact was 10 percent or less (Table 2). Crossing experiments have confirmed that reduced sensitivity to HPPD inhibitors can be transferred to progeny, providing additional evidence that this population is resistant to this herbicide site-of-action family. Additionally, research has demonstrated that the resistance mechanism can be transferred by both seed and pollen.

Table 1 ■ Control of two HPPD-inhibitor-sensitive populations (WCS and ACR) and three accessions (12, 15, and 16) of the HPPD-inhibitor-resistant MCR population 21 days after treatment with an HPPD inhibitor ± atrazine under greenhouse conditions.

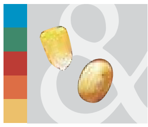
			MCR		
Treatment[a]	**WCS**	**ACR**	**12**	**15**	**16**
Impact	100	96	36	42	58
Impact + atrazine	100	98	43	54	64
Laudis	100	94	17	35	31
Laudis + atrazine	100	100	51	75	89
Callisto	100	88	13	26	27
Callisto + atrazine	100	98	70	51	78

[a] Impact, Laudis and Callisto were applied at 0.75, 3 and 3 fl oz/acre, respectively.

Diversified weed management programs will become increasingly common as the Illinois weed spectrum continues to adapt to modern agronomic crop production practices. Herbicides with soil-residual activity represent opportunities to integrate multiple herbicide modes of action into corn and soybean production practices. These products can reduce the potential for weed interference to reduce crop yield, and represent viable options to manage weed biotypes resistant to several widely used foliar-applied herbicides.

Table 2 ■ Results of field research (2010) to evaluate control of a McLean County waterhemp population with three foliar-applied HPPD-inhibiting herbicides.

Treatment	Rate		% Control			
	lb ai/A	Product/A	7 days after treatment		14 days after treatment	
			alone	w/ atrazine	alone	w/ atrazine
Callisto	0.094	3 fl oz	12	13	10	13
	0.188	6 fl oz	10	25	12	32
	0.375	12 fl oz	13	38	25	52
Laudis	0.082	3 fl oz	10	22	8	18
	0.164	6 fl oz	8	30	10	32
	0.328	12 fl oz	15	27	17	40
Impact	0.016	.75 fl oz	8	7	5	5
	0.033	1.5 fl oz	10	12	8	10
	0.066	3.0 fl oz	10	17	12	23



Corn and Soybean Returns

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In recent years, there have been shifts of acres between corn and soybeans. Some of this shifting likely is due to the relative profitability of the two crops. In this paper, corn returns are compared to soybean returns in four regions of Illinois using a measure called "corn-minus-soybean returns." Corn-minus-soybean returns equal corn returns minus soybean returns, with positive values indicating that corn is more profitable than soybeans and negative values indicating that soybeans are more profitable than corn.

Historic corn-minus-soybean returns are shown for the years between 2000 through 2010. Since 2006, corn-minus-soybean returns have averaged higher than during the 2000-2005 period. While corn is generally more profitable, relative returns between corn and soybeans vary. In some years, soybeans are more profitable than corn.

Projected 2011 returns also are presented. Projected 2011 returns made in November 2010 suggest that corn will be more profitable than soybeans. This, however, is not unusual. Most projections since 2006 indicate that corn will be more profitable than soybeans. Those years in which soybeans turn out to be more profitable than corn likely are not predictable before planting. Therefore, basing acreage decisions on long run considerations—such as rotations impacts on machinery complement and yields—seem prudent.

Historic Corn-Minus-Soybean Returns

Table 1 shows historic corn-minus-soybean returns for northern Illinois, central Illinois, and southern Illinois. Central Illinois is divided into two regions based on soil productivity. Corn yields in the "central-high" region averaged 188 bushels per acre from 2005 through 2009 while yields in the central-low region averaged 177 bushels per acre. These returns are summarized from farms enrolled in Illinois Farm Business Farm Management (FBFM).

For all regions, corn-minus-soybean returns averaged positive from 2000 through 2010. The average corn-minus-soybean return was $44 per acre in northern Illinois, $37 per acre in central Illinois with high productivity farmland, $23 per acre for central Illinois with low productivity farmland, and $27 per acre for southern Illinois (see Table 1).

In mid 2000s, corn became increasingly used in ethanol production at the same time export demands for corn remained robust. As a result, relative crop profitability has changed, with corn becoming more profitable than soybeans. In northern Illinois, for example, corn-minus-soybean returns averaged $26 from 2000 through 2005. The average corn-minus-soybean returns then increased to $66 per acre from 2006 through 2010, an increase of $40 per acre over the 2000-05 average (see Table 1). Similar increases occurred in all regions: corn-minus-soybean returns in central Illinois with high productivity farmland averaged $26 in 2000-05 and $50 from 2006-10, in central Illinois with low-productivity farmland averaged $6 from 2000-05 and $45 through 2006-10, and in southern Illinois averaged $0 per acre from 2000-05 and $59 from 2006-10.

While corn has become relatively more profitable in the late 2000s, that does not mean that there were not years in which soybeans were more profitable than corn. In 2009, soybeans were more profitable than corn in northern and central Illinois. In 2009, corn-minus-soybean returns were -$86 per acre in northern Illinois, -$95 in central Illinois with high productivity farmland, and -$84 in central Illinois with low productivity farmland (see Table 1). Three factors contribute to soybeans being more profitable than corn: 1) nitrogen fertilizer costs were high, 2) corn moisture levels were high leading to high drying costs, and 3) soybeans prices increased relative to corn prices.

Table 1 ■ Historic Corn–Minus–Soybean Returns by Region of Illinois.

	Region			
Year	**North**	**Central-High**	**Central-Low**	**South**
		$ per acre		
2000	22	30	30	25
2001	–0	13	–7	4
2002	21	–6	27	–34
2003	62	59	–57	–11
2004	47	37	52	39
2005	5	24	–11	–24
2006	73	50	57	30
2007	90	98	77	80
2008	96	118	83	67
2009	–86	–95	–84	5
2010P	159	78	90	116
Average for:				
2000–10	44	37	23	27
2000–05	26	26	6	–0
2006–10	66	50	45	59

Source: Illinois Farm Business Farm Management.

Corn-Minus-Soybean Return Projections for 2011

Projections for 2011 corn-minus-soybean returns are shown in Table 2. These projections were made using adjusted-basis futures prices prevalent during the month of November 2010. A price of $4.80 was used for corn and $11.80 per bushel is used for soybeans. Yields were projected at trend-line levels and range from a high of 195 bushels for central Illinois for high-productivity farmland to a low of 160 bushels per acre for southern Illinois. Non-land costs were taken from University of Illinois crop budgets. Corn-minus-soybean returns were projected using 2011 crop budgets available on *farmdoc* (in the management section, see the "Historic Corn, Soybeans, Wheat, and Double-crop Soybeans (PDF)" link in the *Illinois Farm Management Handbook*).

Comparisons of projected returns to historical averages are:

1. In northern Illinois, the projected 2011 corn-minus-soybean return of $114 per acre is $48 higher than the 2006-2010 average of $66 per acre.
2. In central Illinois on high-productivity farmland, the projected 2011 corn-minus-soybean returns of $87 per acre is $37 higher than the 2006-2010 average corn-minus–soybean return of $50 per acre.
3. In central Illinois on low-productivity farmland, the projected 2011 corn-minus-soybean returns of $82 per acre is $37 higher than the 2006-2010 average of $45 per acre.
4. In southern Illinois, the projected 2011 corn-minus-soybean returns of $59 per acre is equal to historical average.

Accuracy of Projections

The above projections were made using futures prices during November 2010. As conditions change, futures price may indicate that relative profitability changes as well. To illustrate, projections of corn-minus-soybean returns are shown in Table 3 for central Illinois with high productivity farmland. These projections were made for five years between 2006 and 2010. These projections were made in four different months prior to harvest: November, January, March, and May. The months November, January, and March were selected because they are prior to planting, allowing farmers to adjust planting decisions. In May, minor changes may still be possible.

Table 2 ■ Projected 2011 Corn-Minus-Soybean Returns by Region of Illinois.

		Illinois Region[1]			
		North	Central-High	Central-Low	South
Corn Yield	Bushels per acre	193	195	185	160
Soybean Yield	Bushels per acre	54	56	53	47
Corn Price	$ per bushel	$4.80	$4.80	$4.80	$4.80
Soybean Price	$ per bushel	$11.80	$11.80	$11.80	$11.80
Corn Non-land Costs	$ per acre	$488	$482	$465	$468
Soybeans Non-land Costs	$ per acre	$313	$294	$284	$314
Corn-Minus-Soybean Returns[2]	**$ per acre**	**$114**	**$87**	**$82**	**$59**
Average Corn-Minus-Soybean Return from 2005 through 2010	$ per acre	$66	$50	$45	$59

Source: Taken from Revenue and *Costs for Corn, Soybeans, Wheat, and Double-Crop Soybeans.* Department of Agricultural and Consumer Economics, University of Illinois, available in Farm Management Handbook in Management Section of farmdoc (www.farmdoc.illinois.edu)

[1] Central-high and central-low are distinguished by soil productivity.

[2] Equals corn yield x corn price—corn non-land cost—soybean yield x soybean price + soybean non-land costs.

To illustrate the projections, take 2006 as an example. In 2006 actual corn-minus-soybean returns was $50 per acre (see Table 3). The projection of 2006 corn-minus-soybean returns made in November 2005 was -$18 per acre, $68 lower than actual corn-minus-soybean returns. The 2006 projected corn-minus-soybean return is -$23 per acre in January, $12 in March, and $24 in May.

Projections in Table 3 were made using the following process:

1. In each projection month, futures prices were taken from Chicago Board of Trade (CBOT) during the first day of the month. Prices were collected from the December corn contract and November soybean contract. In November 2005, for example, prices on the Dec 2006 corn contract and November 2006 soybean contract were collected to project 2006 harvest prices.
2. The basis was subtracted from the futures price to arrive at a projected cash price used in projections.
3. Projected yields for the upcoming year were based on trend line yields.
4. Costs were estimated based on University of Illinois budgets prior to harvest. Note that these budgeted costs were not the same as actual costs because they were done before planting and harvesting were completed.

Since 2006, all projections indicate that corn is more profitable than soybeans. This likely reflects the fact that corn will normally be more profitable than soybeans. The negative projections in 2006 may have resulted because 2006 could be considered a transition year. Prior to 2006, different historical relationships existed than post 2006.

The worst year for predictions was 2009. During 2009, corn-minus-soybean returns were negative while all predictions were for positive corn-

Table 3 ■ Actual and Projected Corn-Minus-Soybean Returns, Central Illinois with High-Productivity Farmland, 2005–2010.

	Year				
	2006	2007	2008	2009	2010
			$ per acre		
Actual	50	98	118	–95	78
Projection made in:					
November	–18	103	54	114	93
January	–23	132	71	80	104
March	12	187	87	51	71
May	24	132	328	71	26
Actual minus projection made in:					
November	68	–5	64	–209	–15
January	73	–34	47	–175	–26
March	38	–89	31	–146	7
May	26	–34	–210	–166	52

minus-soybeans returns. This occurred because the conditions resulting in negative corn-minus-soybean returns were not evident prior to planting of the 2009 crop. For example, the budgets did not contain higher drying costs for corn that occurred in2009 due to high moisture levels in corn during the 2009 harvest. This result may indicate that it will be difficult to predict years in which relative profitability changes between corn and soybeans.

Another poor projection occurred in May 2008. The May 2008 projection of corn-minus-soybean returns was $301 per acre, considerably higher than all other projections and considerably higher than the 2008 actual projection of $118 per acre. This was a period of substantial run-up in commodity prices. Futures prices used in projections were $5.89 per bushel for corn and $11.48 for soybeans. This may suggest that abnormally high prices should not be used in projections of relative crop profitability.

Summary

On average, corn is more profitable than soybeans in all areas of Illinois. Relative profitability of corn has increased since 2006. Between 2006 and 2010, corn-minus-soybean returns averaged $66 per acre in northern Illinois, $50 in central Illinois with high productivity, $45 per acre in central Illinois with low productivity, and $59 per acre in southern Illinois.

The average differences in profitability between 2006 through 2010 likely will persist into the foreseeable future. That is, corn is likely to be more profitable than soybeans by $66 in northern Illinois, $50 in central Illinois with high-productivity farmland, and $45 per acre in central Illinois with low-productivity and $59 in southern Illinois. In any given year, relative profitability will differ from historical averages. However, there likely will not be information prior to planting that will indicate differences from historical averages. Until demand conditions change or relative yields change, corn will likely be more profitable in Illinois.

The results also suggest that the corn-soybean rotations likely should be based on factors other than current market conditions. Corn will likely be more profitable than soybeans in most years, perhaps leading famers to plant more corn than soybeans in all years. However, other factors should also enter this decision. These could include additional machinery requirements for higher amounts of corn, which could lead to higher overall costs, mitigating the profit advantages of growing corn. Also corn-after-corn and corn-after-soybeans should enter into the long-run decision of which crops to plant in rotation.

A “Formula” for High Corn Yield?

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There has been a flurry of publicity recently to promote the fact that data from “addition” and “deletion” studies show that adding high levels of individual inputs produces yield increases only if other inputs are also at high levels. Such results can be assembled into a pleasing “formula” that says that high yields will follow when inputs such as hybrid, N rate, row spacing, plant population, and foliar fungicide are all aligned to eliminate yield limitations that occur under “normal” management.

Another consequence of the promotion of the use of “high-input packages” is the implication that much of the research that has been done in recent years, if not accompanied by high input levels, may not be valid. In this view, trying to find optimum levels of, say, plant population produces invalid findings unless all inputs are maintained at high levels, according to the “formula.” While there is little proof that this is indeed the case, the contention has some questioning much of the data on which corn crop management decisions rest today.

One Study of Input Combinations

Seven or eight years ago we initiated a series of studies on continuous corn in which we used “normal” and “high” levels of tillage (normal = fall chisel; high = deeper or more thorough tillage); fertilizer (normal = 220 lb N plus normal levels of P and K; high = 320 lb of N plus additional P and K); and plant population (normal = 32,000; high = 40,000 plants per acre at harvest). Studies were placed in productive soils at the Crop Sciences research centers at Perry, Urbana, Monmouth, and DeKalb, choosing to stay mostly in the northern half of Illinois because continuous corn is much more common there. Plots stayed in the same place each year, and treatments were arranged in a 2 × 2 × 2 factorial, with eight treatment combinations to allow us to see interactions—that is, whether changing levels of one variable affected the response to other factors.

On average over 16 site-years, yields were about 4 bushels per acre higher with deeper or more thorough tillage, but this difference was not significant (that is, we can’t say for certain it was due to treatment and not to random

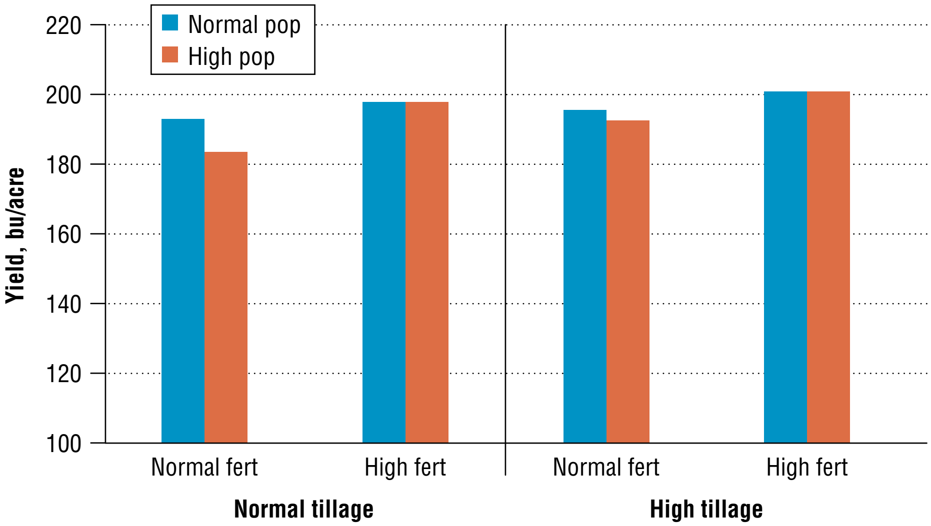

Figure 1 ■ Yields of continuous corn with and without additional tillage, fertilizer, and plant population, averaged over 16 site-years in Illinois.

chance). Adding an extra 100 lb N plus more P and K increased yields by about 8 bushels per acre, and raising the population from 32,000 to 40,000 actually decreased yields, by about 3 bushels per acre (Figure 1). The only interaction that we found was that raising the plant population decreased yield by about 6 bushels per acre under normal fertility levels, but had no effect on yield under high fertility levels.

To see if the effects of these input levels were related to yield levels, we looked at "all high" versus "all normal" yields over the 16 site-years of this study. While some of the highest-yielding sites showed some of the larger responses to the "package" of high inputs, there was not a clear indication that yield increases from adding more inputs occurred only at high yield levels (Figure 2.) While this study was designed to be "high-yielding", yields ranged from about 100 to 250 bushels per acre, and averaged less than 200 bushels per acre. But even when conditions were good for high yields, adding additional inputs did not produce the large yield increases some might have expected.

We continued this study up to the present, but switched in 2008 from deep tillage to strip-till, kept the fertilizer response variable, and added foliar fungicide—none versus the labeled rate—as a replacement for the plant population variable. Over 12 site-years since, we have found a larger response to added fertilizer—about 16 bushels per acre—than we saw during the previous phase of the study. Foliar fungicide produced an average yield increase of 8 bushels per acre, but the response to fungicide was almost exactly the same at the high rate of fertilizer as at the low rate of fertilizer (Figure 3.) Thus it does not appear, at least in a general sense, that raising the level of one input, such as fertilizer N, routinely calls for adding or raising the levels of other inputs.

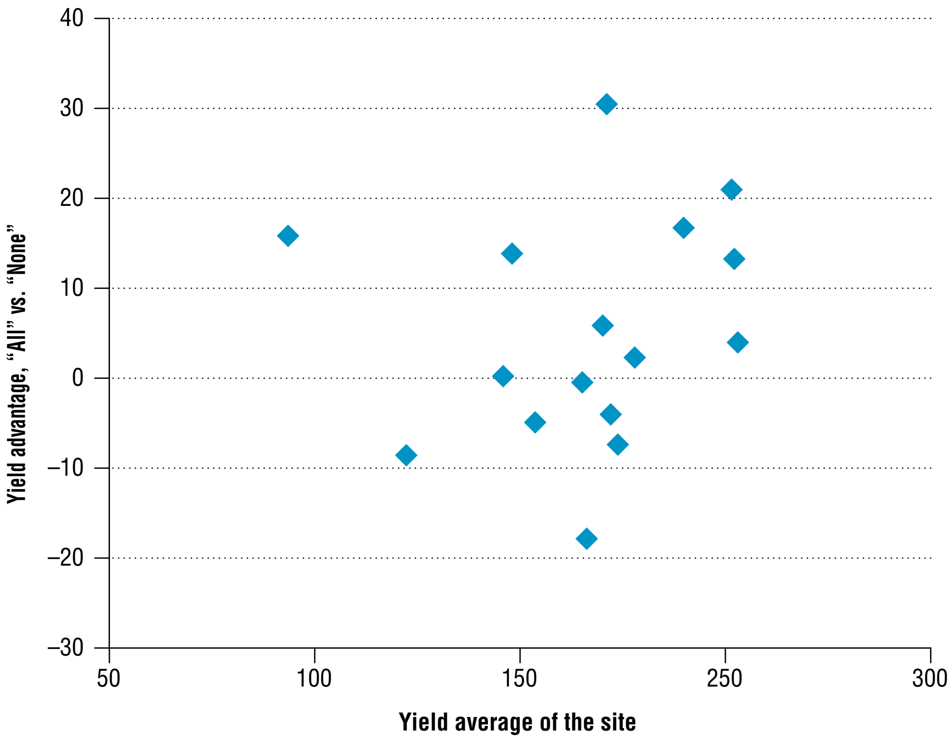

Figure 2 ■ Data by site-year showing yield responses going from "all normal" (none) to "all high" (all) input levels in 16 Illinois trials.

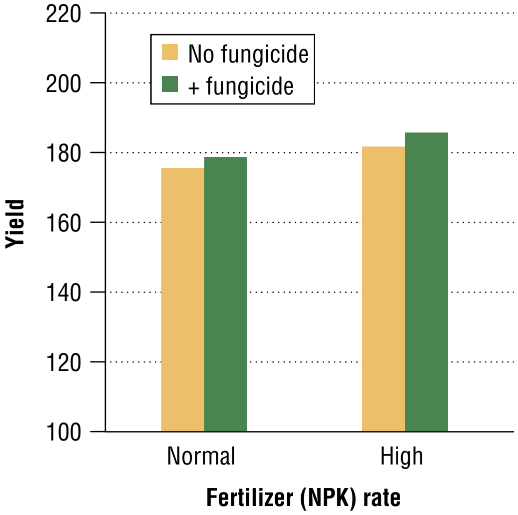

Figure 3 ■ Response of continuous corn yield to fertilizer rate (normal = 220 lb N; high = 320 lb N) and foliar fungicide. Data are averages over 12 Illinois trials from 2007 through 2010.

The idea that high-yielding corn needs more "protection" from an input like fungicide is also not very well supported by these data. As shown in Figure 4, response to fungicides was affected little by yield level, at either fertilizer rate.

Hybrids and Their Management

With the advent of genetically-modified hybrids, the recent proliferation of traits and combinations of traits for insect and herbicide resistance, and announcement of novel traits (such as drought tolerance) on the way, a logical question is whether or not we are missing the boat by using data generated with hybrids in use only a few years ago.

While it is clear that hybrids have been substantially improved in recent years, it is less clear that adding insecticidal (Bt) traits and herbicide resistance traits has contributed much to yield potential. They have effectively protected the crop, thereby protecting (and increasing) yield when the insect pests they control are present. In the 2010 University of Illinois hybrid trials, different groups of traits did not have consistent yield advantages or disadvantages over other groups (Table 1). This occurred in a year with low levels of insect pressure. It is clear that performance of hybrids based on their genetics remains a major determinant of their yield potential.

Figure 4 ■ Response to foliar fungicide at normal and high fertilizer rates, as affected by yield level of 12 Illinois sites. Data in Figure 3 are averages of these data.

Table 1 ■ Average yields by (insecticidal) trait group in the University of Illinois corn hybrids trials in 2010.

	South		Central-East		Central-West		North	
Trait set	**No.**	**Yield**	**No.**	**Yield**	**No.**	**Yield**	**No.**	**Yield**
None	8	218	8	214	11	215	18	211
CB	22	222	3	213	8	206	7	224
CB2-RW	1	226	2	221	2	215	2	213
CB2-RW2			2	185	2	211	1	186
CB2-RW2-LP	1	224	2	200	2	223	3	208
CB2-RW2-LP2			1	218	1	200	1	212
CB2-RW3	8	221	9	217	9	212	10	223
CB-LP	2	219	1	216	1	224		
CB-RW	28	218	64	211	62	211	56	213
CB-RW2-LP	5	220	6	221	6	213	6	214
CB-RW-LP	9	227	19	217	20	213	7	216
RW			1	216	1	238	1	212

CB = corn borer Bt; RW = Corn rootworm Bt; LP = Lepidopteran Bt. Numbers show number of different traits.

But should different hybrids be managed differently? Obviously, hybrids with serious genetic deficiencies are less likely than better hybrids to be able to respond to management inputs when conditions are favorable. It is less clear that commercial hybrids will respond so differently and consistently to management inputs that we need to do major resets of inputs when we change hybrids. In one study in Illinois in 2010, though, different hybrids responded quite differently to plant population (Figure 5).

Studies that examine the interaction of hybrids and management factors, including how these interact with different environments (fields and years) are important to see whether or not we need to be changing management as hybrids change and other inputs become available, or become more or less costly in comparison the product (corn grain) they are meant to affect. *In general, studies such as these have shown that, while interactions between and among factors often are found, they tend to repeat poorly over fields and years.*

Formula?

This lack of consistency means that using a "formula" that includes increasing levels of many inputs, while it may be effective in increasing returns under some conditions, may not be an effective strategy to raise returns under the wide range of environments under which corn is produced. If we can at least partly control environments—for example, by irrigating—then we can expect much more consistent responses to increased levels of some inputs, though such responses are not always as consistent as we expect. But adding high input levels to a field that averages 150 bushels per acre will in many, if not most, cases result in either no yield increase or in yield increases too small to cover the added costs.

As a final note, using "two-rate" trials to find the best level to use of inputs such as fertilizer N or plant population is unsound. As a first look, using populations of, say, 30,000 and 40,000 in a trial just to show that population as a variable interacts with other variables can be instructive. But if we want to

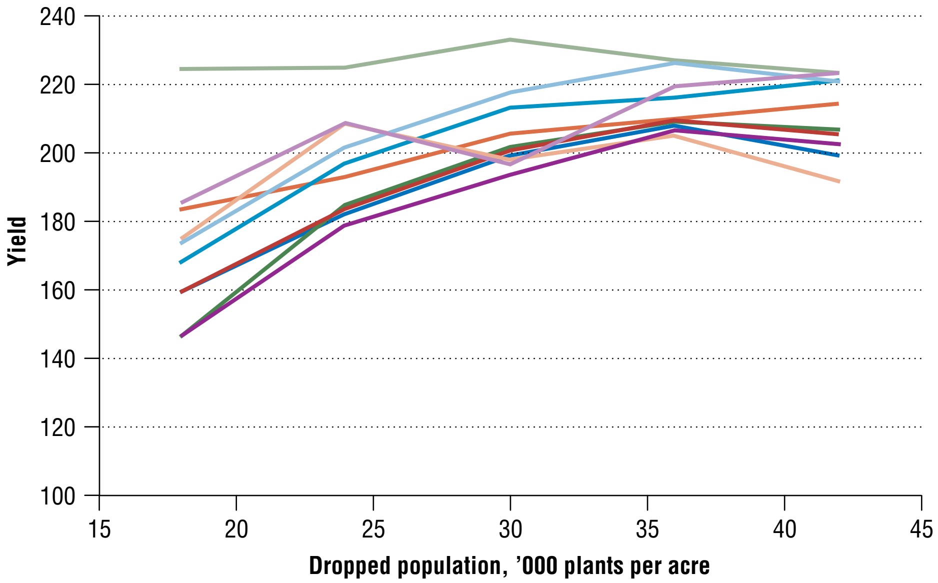

Figure 5 ■ Plant population responses of corn hybrids, averaged over four Illinois locations in 2010. Each line represents a different hybrid.

know what population the crop should be grown at in actual fields, we need a lot of studies done under actual field conditions, using a range of populations starting from low and going to high, and with at least five or six populations in between. Such a design is necessary in order to produce a response curve that allows us to choose the best population for maximum return to seed. There is no substitute.

Soybean Agronomics

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Soybean seeding rates in Illinois have typically ranged from 150 to 200% of the number of plants needed at harvest to maximize yield. High seeding rates provide 'insurance' against conditions that reduce soybean emergence. The cost of soybean seed was historically a relatively minor expense to the cropping operation. The practice of dramatically over-seeding was therefore a good decision from both an agronomic and economic point-of-view. However, soybean seed costs are five-fold greater today than 15 years ago. These higher seed costs have increased interest in reduced seeding rates to maximize economic returns. As a background to this research, data were compiled from three different experiments representing 50 site-years of data. These fifty site-years represent many different locations throughout Illinois, several different growing seasons ranging from 1998 to 2009, multiple row spacings (7.5″, 15″, and 30″), and some different fungicide seed treatment applications. In all cases, the data were balanced and interactions were non-significant; therefore, pooling the data to analyze yield response to seeding rate was statistically valid. Those results showed a rather wide variation around an expected yield given any seeding rate in the range of 50,000 to 200,000 seeds/acre across a wide range of conditions (Figure 1). Most importantly, the variation of the data across the whole range of seeding rates was constant, meaning there was just as much yield variation at the high seeding rates as the low seeding rates. This suggests there was not that much greater 'insurance' for starting with higher seeding rates.

Those previous trial results compiled over the last decade have provided useful information; however, none of those trials included planting date as a factor. Moreover, several factors in addition to seed costs have changed over the last decade, including newer genetics, fungicide and insecticide seed treatments as a more common practice, and the desire to plant earlier to increase yields. Furthermore, fuel and labor costs have continued to increase and many growers are switching, or are interested in switching, to 30″ row planters versus narrow-row drills. Due to these circumstances, research

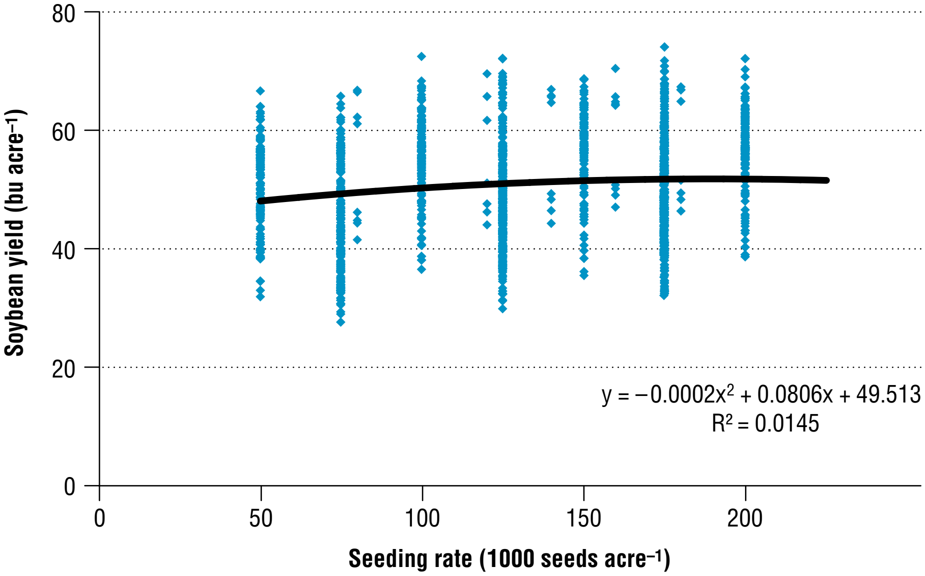

Figure 1 ■ Soybean yield data for seeding rates ranging from 50,000 to 200,000 seeds per acre collected from 50 site years from 1998 to 2009 throughout Illinois including drilled (7.5”), 15”, and 30” row spacings, and different fungicide seed treatments.

trials were located at five locations throughout Illinois in 2010 to study the interactions among the soybean agronomic decisions of planting date, seeding rate, and row spacing.

Materials and Methods

Trials were established at the DeKalb, Monmouth, Perry, Urbana, and Dixon Springs University of Illinois Agronomy Research Centers. A locally competitive glyphosate-resistant variety with a mid-ranged adapted maturity group was planted at each location. Seeds were treated with a fungicide + insecticide seed treatment at all locations except Urbana. All locations were conventionally tilled, and weed pressure was minimized by preemergence residual herbicides and postemergence glyphosate as needed. There were four planting dates, mid-April, early-May, late-May, and early-June each with three seeding rates, 70,000; 120,000; 170,000, and in 15″ and 30″ wide rows. At Dixon Springs, an additional 10,000 seeds/acre was planted at all three rates. The two row widths, 15″ and 30″, were planted with the same planter at each location. Each treatment was replicated four times for a total of 96 plots. Plots were a minimum of 10´ x 30´. We collected initial stand counts (between V1–V2), final stand counts (R7–R8), and seed yield.

Data Presented from 2010 Research

All trials were initiated and maintained with no confounding problems that would cause any concern over data validity. These data clearly represent the importance and differences due to agronomic decisions experienced in 2010. However, these data were still from only one growing season, therefore, some caution should be taken against using these data with too much emphasis on prediction. In general, early planting dates were established in seasonably warm soils, but the early and middle part of May presented cool temperatures and moist-to-saturated soils at most locations. Late-season weather conditions were generally seasonably warm with normal to less-than-normal rainfall at most locations. Overall, yield levels were average to above average for all locations. Data analyses revealed that DeKalb, Monmouth, Urbana, and Perry had similar yield levels and data combined appropriately across those locations. Dixon Springs had lower overall yield levels, and planting dates were slightly delayed compared with the other locations, therefore, data from Dixon Springs are presented separately.

There were no significant interactions between planting date, seeding rate, and row width. Furthermore, planting date was the only effect significant at the alpha=0.05% level (Table 1).

Seed yield decreased 0.18 bu/day from mid-April to early-May, 0.35 bu/day from early-May to late-May, and 0.51 from late-May to mid-June for DeKalb, Monmouth, Urbana, and Perry locations (Figure 2). Seed yield decreased 0.2 bu/day on a linear trend from early-May to late-June at Dixon Springs.

As indicated previously, there was no difference in yields between 15″ and 30″ row widths so yield data are not presented. There was also little influence on yields due to seeding rate. Seed yield was 1.4 bu/acre higher for seeding 170,000 versus 70,000 seeds per acre at DeKalb, Monmouth, Urbana, and

Table 1 ■ Analysis of variance for the influence of row widths, seeding rates, and planting dates on soybean seed yield collected from 2010 trials conducted at DeKalb, Monmouth, Urbana, Perry, and Dixon Springs, Illinois.

Type 3 Tests of Fixed Effects

		DeKalb, Monmouth, Urbana, and Perrry			Dixon Springs		
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**	**Den DF**	**F Value**	**Pr > F**
width	1	345	2.42	0.121	67	0.11	0.743
rate	2	345	2.49	0.084	67	1.64	0.202
width*rate	2	345	0.47	0.626	67	0.14	0.871
date	3	345	176.98	<.0001	67	12.29	<.0001
width*date	3	345	1.12	0.340	67	0.42	0.736
rate*date	6	345	0.77	0.591	67	0.53	0.785
width*rate*date	6	345	1.25	0.282	67	0.88	0.512

Perry locations (Figure 3). Seed yield increased 2 bu/acre at Dixon Springs for increasing seeding rates from 80,000 to 180,000 seeds/acre.

Conclusions

If soybean seeds are planted at rates greater than necessary, then dollars are lost. If soybean planting dates are delayed too long into the season, then yield and subsequently money is lost because all other input costs remain equal. This clearly reduces the return on investment for the grower. Data presented were collected from one growing season and clearly need to be further investigated

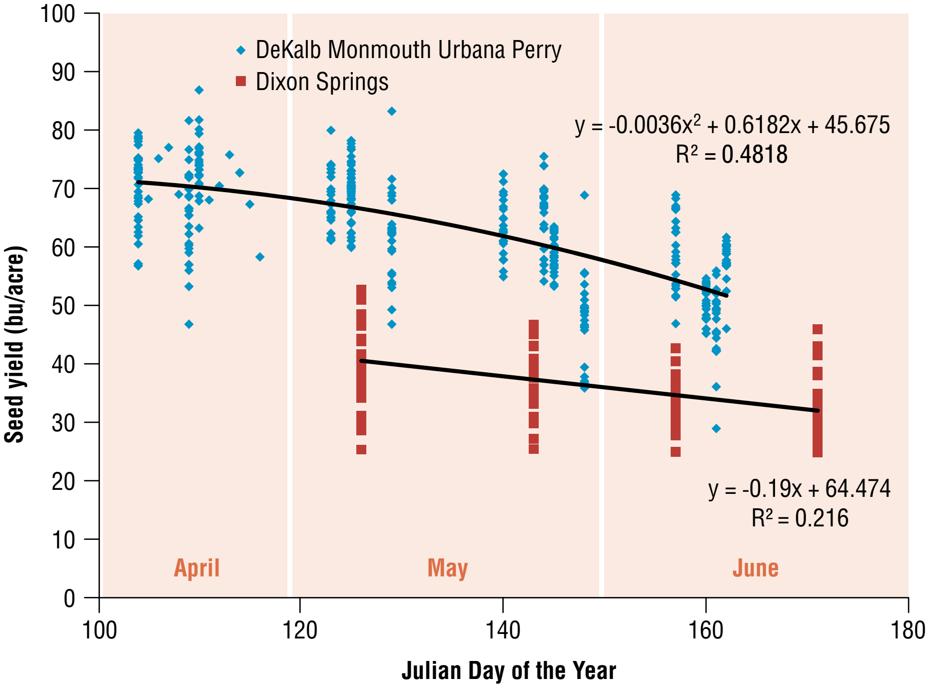

Figure 2 ■ Influence of planting date on soybean seed yield from 2010 trials located at DeKalb, Monmouth, Urbana, Perry, and Dixon Springs, Illinois. Data from the Dixon Springs location were analyzed separately due to overall lower yields and later planting dates in relation to the other locations.

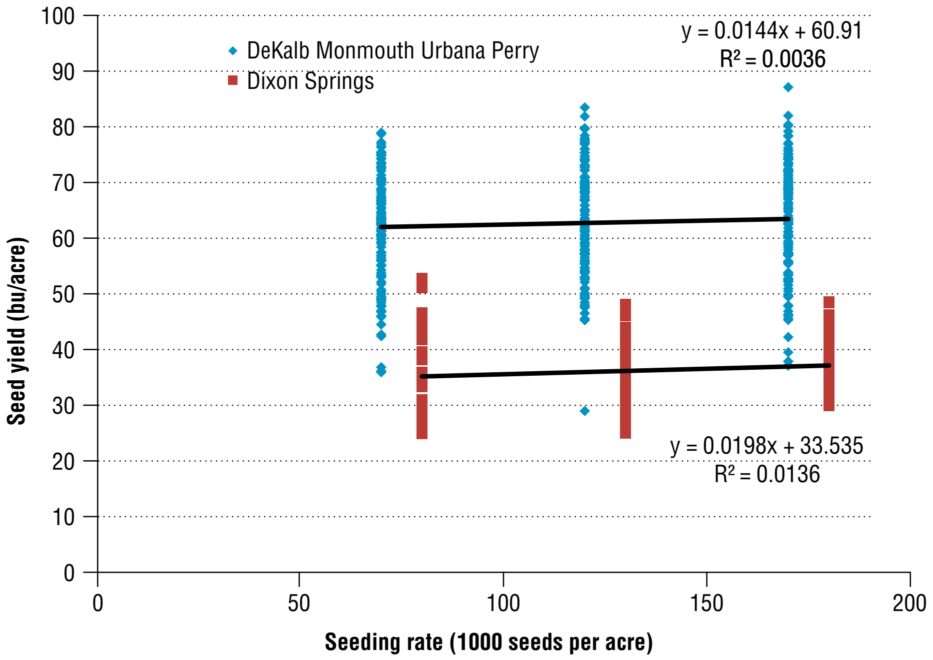

Figure 3 ■ Influence of seeding rate on soybean seed yield from 2010 trials located at DeKalb, Monmouth, Urbana, Perry, and Dixon Springs, Illinois. Data from the Dixon Springs location were analyzed separately due to overall lower yields in relation to the other locations.

due to the economic importance of maximizing return on investment in relation to agronomic decisions. However, as an example, if a couple of assumptions are made, such as, current seed costs of $0.38/1000 seeds (current costs reported by University of Illinois FarmDoc website: http://www.farmdoc.illinois.edu/), and $10.00/bu soybean, then these data would be interpreted to suggest that a grower (in the northern 2/3 of the state) that planted 70,000 seeds per acre on April 20th would have profited $214.60 more per acre than a grower that planted 170,000 seeds per acre on June 12th, regardless of row widths. Most of this difference would be related to planting date. I am NOT recommending seeding rates that low, but where seeding rate recommendations should be in that range will be further discussed with more data on the relationships between seeding rates and early- and late-season stand establishments.

We thank the Illinois Soybean Association for partially funding this research through the soybean checkoff.

ILLINOIS SOYBEAN ASSOCIATION

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